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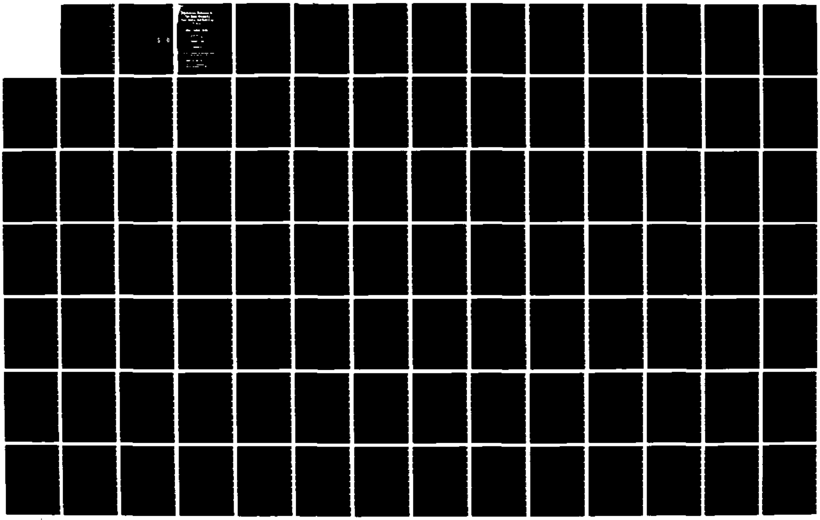

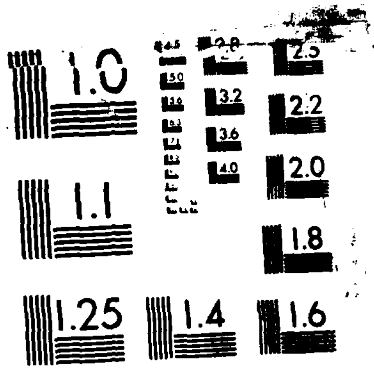

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VOLUME II

ANNUAL SUMMARY REPORT

Walter Kroll
William L. [illegible]

FEBRUARY 1982

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Results of Year 2 are presented and includes: (a) the theoretical rationale and strategy for analysis of neuromotor coordination mechanisms in fast limb movements; (b) a progress report of experimental and modelling studies conducted during Year 2; (c) an article describing an EMG-level mathematical model of fast arm movement; (d) an article describing the stability of delay equations for simple human stretch reflexes; (e) an article describing

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE theoretical bases for the sensory imparted learning model; (f) an article describing the prediction of male and female isometric arm strength through anthropometric measures; (g) experimental results of gender differences and muscle fatigue effects upon speed of neuromotor coordination mechanisms; and (h) experimental results of muscle fatigue upon speed of movement and the effects of tonic vibratory response upon neuromotor coordination mechanisms.

APPENDIX E

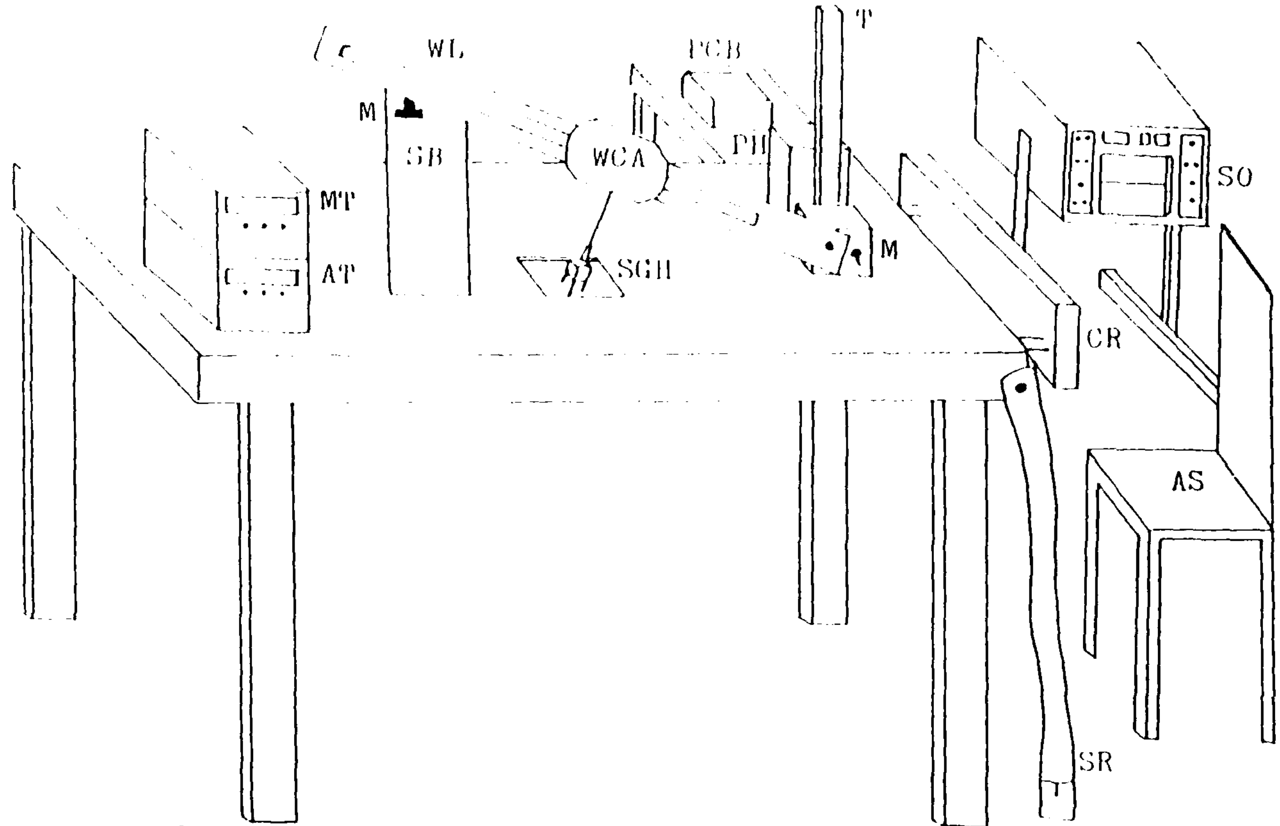
GENDER DIFFERENCES AND EFFECTS OF ISOMETRIC FATIGUE AND RELATIVE ISOMETRIC FATIGUE ON THE MAXIMUM SPEED OF HUMAN FOREARM FLEXION UNDER RESISTED AND UNRESISTED CONDITIONS

Movement Selection

In order to maximize the stopping action of the antagonists, the movement selected for this investigation is classified as class B according to the classification scheme of Bailey and Presgrave (5). Class A movements are defined as those stopped by impact with an object. Class B movements are those stopped by antagonistic muscle action. The selection of forearm flexion also satisfied the characteristics established by Wilkie (100): (1) a geometrically simple joint, (2) a limited number of muscles, each having a small origin and insertion, (3) exerts no effect on the rest of the body, and (4) involves light skill, i.e. easily replicated. Lagasse (54) and Wolcott (103) both studied forearm flexion with the upper arm abducted at right angles to the body and in line with the shoulder. The termination of the movement differed in that Lagasse investigated a class B movement, while Wolcott investigated a class A movement. The availability of previously used apparatus lead to the selection of forearm flexion in the sagittal plane, rather than the horizontal plane. This decision subjected the movement to the influence of the force of gravity. This consequence was recognized and acknowledged as a limitation. However, gravitational influences are indigenous to human movement and, therefore,it was not a limitation which necesitated compensation (103).

Semi-pronation of the hand was used as the testing position, in agreement with Lagasse (54) and Wolcott (103). This position was used in all phases of testing, as it was considered the most comfortable and controllable for all subjects.

The forearm was resting on a stationary block, flexed to an angle of 160 degrees with the upper arm, at the start of each speed of movement trial. The upper arm was extended forward, in line with the shoulder, forming an angle of 90 degrees with the trunk. From the starting position, the subject was required to flex through at least 70 degrees and to volitionally stop at a target placed at 90 degrees(see Fig. 1). Since this investigation was interested in maximizing the action of the triceps, the subject was required to flex his or her arm as quickly as possible without overshooting the ninety degree target. The target was flexible and the subject was not physically prevented from overshooting ninety degrees.



LEGEND:

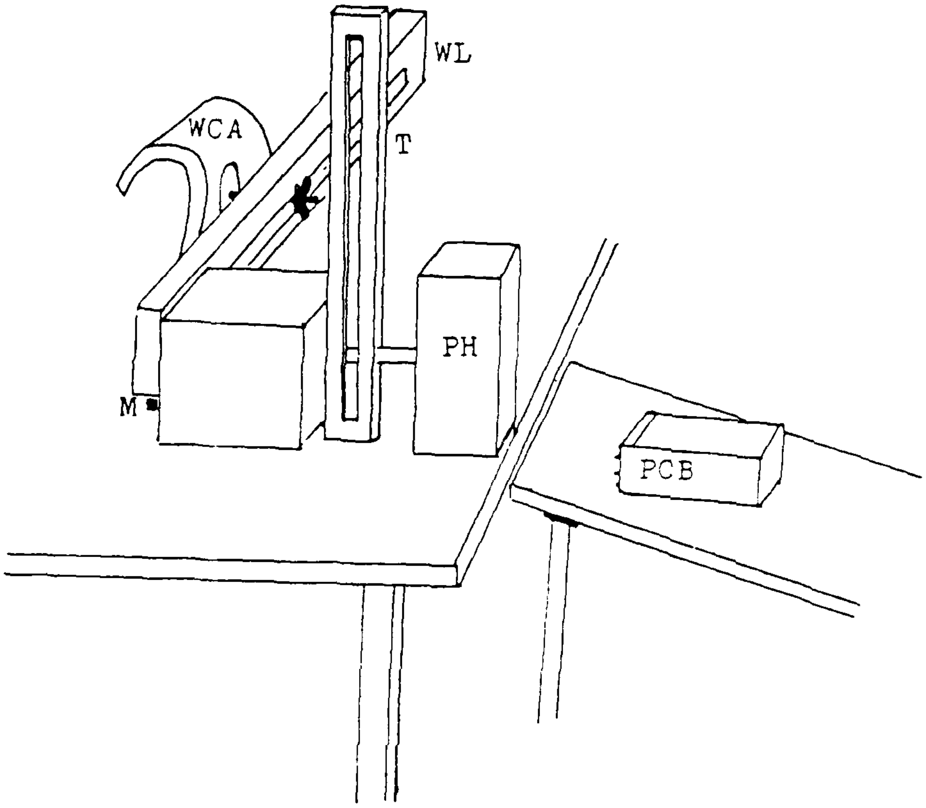
AS - ADJUSTABLE SEAT
AT - ACCELERATION TIME CLOCK COUNTER
CR - CHEST REST
M - MICROSWITCH
MT - MOVEMENT TIME CLOCK COUNTER
PCB - POTENTIOMETER CONTROL BOX
PH - POTENTIOMETER HOUSING
SB - STARTING BLOCK
SR - SAFETY RESTRAINT
SGH - STRAIN GAUGE HOUSING
SO - STORAGE OSCILLOSCOPE
T - TARGET
WCA - WRIST CUFF ASSEMBLY
WL - WOODEN LEVER ARM

Fig. 1. Testing Apparatus - Side View.

Movement Apparatus

Apparatus previously used in investigations by Lagasse (54) and Wolcott (103) was modified, whenever necessary, for this investigation (see Fig. 2). The monitoring apparatus was attached to the top of table which in turn was secured to the floor. A light weight piece of pine wood, 50 cm. in length, 3.5 cm. in width, and 2.5 cm. across the top, formed the lever arm. The lever arm was reinforced with two strips of aluminum attached to the top and the bottom. The base of the wooden lever was attached to an axle mounted in essentially frictionless oil bearings. The middle section of the bar was slit to allow for the adjustment of the wrist cuff and the placement of the inertial loads. The wrist cuff was secured to the inside of the bar, facing the subject's arm, via a wing nut assembly. The inertial loads were also secured, beside the subject's arm, via a wing nut assembly. A wooden block was shaped and secured to the table top, such that when the subject's arm was flexed to 160 degrees, the wooden lever rested on the block. A second wooden block was shaped and secured to the table top, such that when the subject flexed to 90 degrees, the wooden lever arm contacted a flexible rubber target attached to the wooden block.

When the wooden lever arm was lifted from the starting block, a microswitch was released thus closing a circuit and initiating a clock counter. When the subject reached 90 degrees of flexion, a second microswitch was activated, thereby opening the circuit and stopping the clock counter. In this way, the clock counter recorded the time elapsed during 160 to 90 degrees of forearm flexion. An adjustable chest rest, adjustable stool, and an adjustable safety belt were used to properly secure the subject and insure the testing position was identical across all subjects.



LEGEND:

M - MICROSWITCH
PCB - POTENTIOMETER CONTROL BOX
PH - POTENTIOMETER HOUSING
T - TARGET
WCA - WRIST CUFF ASSEMBLY
WL - WOODEN LEVER ARM

Fig. 2. Testing Apparatus - Back View.

Maximum Speed of Movement

Movement time as recorded on the clock counter served as a measure of the maximum speed of forearm flexion through the first 70 degrees of flexion. During the actual execution of the speed of movement trials, the analog displacement recordings clearly showed the subjects' inability to terminate the movement at 90 degrees of flexion. The extent of the overshoot was calculated and will be reported in Chapter 4. Henceforth, movement time will refer to the time elapsed from the onset of movement to the maximal displacement of the forearm.

Assignment of Resistance for Speed of Movement Trials

As discussed by Wolcott (103), any investigation into the effect of inertial loading upon the maximum speed of movement must insure that the loading is identical for all subjects. The variation in limb length must be taken into consideration. Stothart, as reported by Ward (97), used light weights and maximum distances from the elbow, to simulate 2 or 3 times the natural moment of inertia, as load conditions. He reported a decrease in velocity as the load increased. Ward (97) followed by using light weights at long distances and heavy weight at short distances, such that the mathematical calculation of mk^2 was equal. Each multiple of the natural moment of inertia had a short and a long equivalent. The results indicated a significant difference between velocity under short and long loading conditions. The velocity was greater with the longer loading position. This investigation employed the same weight for all subjects and varied the applied distance to produce the required multiple of the natural moment of inertia.

Load conditions were calculated for each subject, specific to the inertia of his or her hand and forearm segment, therefore, the loads were mechanically equivalent for all the subjects. The moment of inertia of the forearm and hand, about the axis of rotation, was calculated according to the procedures outlined by Plagenhoef (73). The mass of the forearm and hand was calculated using body segments as a percentage of the total body weight and using established specific gravity values (73). Multiples of the natural moment of inertia were designated as Load 1 and Load 2. The increase in the natural moment of inertia was achieved by attaching a constant known mass to the subject via the wooden lever arm at a calculated distance from the axis of rotation (103).

The wrist cuff assembly had been found to be equivalent activity from the triceps brachii.

Electromyographic Apparatus

Bioelectric activity was transmitted via silver-silver chloride surface disk electrodes to a Techtronic Two Channel Storage Oscilloscope and a Beckman (type R) Dynagraph Recorder. (Instrument specifications may be found in Appendix D.)

All time relationships between the onset and the termination of bioelectrical activity and elbow displacement were read directly from the oscilloscope and/or dynagraph paper recordings. Prior to all testing sessions an ohm meter (Monarch, Model MP 200 volt) was used to determine skin resistance, below 10k ohms was considered acceptable.

Acceleration-Deceleration Timing Apparatus

The apparatus used to measure the motion parameters was a redesigned version of the apparatus used by Wolcott (103) and Lagasse (54). A potentiometer was encased in a control box and was attached to the axle at the base of the wooden lever. The potentiometer monitored the angular displacement of the lever arm and the attached forearm. The angular displacement signal was electronically differentiated once to give a measure of limb velocity and a second time to give a measure of limb acceleration. The circuitry was designed to initiate a clock counter with the onset of acceleration and to terminate when acceleration was again zero. Thus the clock counter recorded acceleration time or the time to the point of inflection. Since zero acceleration is synonymous with peak velocity, with respect to time, the recorded time was also a measure of the time elapsed from movement initiation to peak velocity.

The apparatus allowed for instantaneous ditigal measures of the time parameters and also allowed for analog recordings of the displacement, velocity, and acceleration curves on the Beckman (type R) Dynagraph.

Agonist and Antagonist Fatigue

Fatigue was induced isometrically in the forearm flexors and extensors in agreement with the protocol established by Lagasse (54). During flexor fatigue, the forearm was positioned at an angle of 160 degrees with the upper arm, which was at right angles with the trunk. The position for flexor fatigue was precisely the same as the starting position for speed of movement trials, also previous studies

(54, 59, 103) have shown the flexors exhibit the greatest bioelectric activity at the start of forearm flexion. During extensor fatigue, the forearm was positioned at an angle of 90 degrees with the upper arm, which was at right angles with the trunk. This position was selected to maximize the effect of fatigue over the range where the extensors exhibit the greatest bioelectric activity during forearm flexion (54, 103). During concurrent flexor and extensor fatigue, the forearm was positioned at an angle of 125 degrees with the upper arm, which was at right angles with the trunk.

Extensor and flexor fatigue was induced using two regimens, 5:5 and 5:10. The 5:5 regimen required the subject to perform a five second maximum voluntary contraction followed by five seconds of rest. This was considered a high intensity fatigue regimen primarily affecting phasic muscle fibers. The 5:10 fatigue regimen required the subject to perform a five second maximum voluntary contraction followed by ten seconds of rest. This less intense fatigue regimen was expected to primarily affect tonic muscle fibers.

The concurrent flexor and extensor fatigue regimen was designated as 5/5:0, that is, 5 seconds of maximal contraction of the elbow flexors followed by 5 seconds of maximal contraction of the elbow extensors. The cycle repeated without a rest interval. Thus, theoretically, a state of fatigue equivalent to a 5:5 regimen was induced concurrently in both elbow extensors and flexors.

Maximum Isometric Strength Assessment

Maximum isometric flexion and extension strength was assessed via a calibrated strain gauge. The wrist cuff assembly allowed for the positioning of a rigid steel bar between the cuff and the strain gauge housing. Exertion on the strain gauge was transmitted to a Beckman (type R) dynagraph and recorded on chart paper. During the assessment of maximum isometric strength, the lower arm formed an angle of 160 degrees with the upper arm, which was at right angles with the trunk. During the assessment of maximum isometric extension strength, the lower arm formed an angle of 90 degrees with the upper arm, which was at right angles with the trunk. In all instances of strength assessment, the strain gauge was positioned normal to the forearm.

Two types of maximum isometric strength were assessed, a maximum voluntary contraction (MVC) required the subject to build up to a maximum exertion and hold for a total of five seconds. A fast maximum voluntary contraction (FMVC) required the subject to explosively generate a maximum exertion, which was terminated after a plateau was observed on the Beckman dynagraph recording.

Testing Procedures

Preliminary testing procedures. During the intial testing session, the subject's personal data was recorded: age, weight, and the length from the olecranon process to the ulnar styloid. The distances for Load 1 and Load 2 were calculated and recorded for subsequent sessions.

The skin surface on the biceps brachii and the triceps brachii was prepared following the generally accepted procedures of Walthard and Tchiacaloff (96). Five silver-silver chloride surface electrodes were prepared with conductive gel and adhesive collars. The pick-up electrodes were placed on central locations on the biceps and triceps. The reference electrodes were placed one to two centimeters distal to the pick-up electrodes. The skin over the right clavicle was suitably prepared and the ground electrode affixed to it. The resistance between the electrodes was measured with an ohm meter, readings below 10k ohms were deemed acceptable.

Following electrode placement, the subject was escorted to the testing table, where instructions regarding susequent procedures were given and the speed of movement apparatus was demonstrated. The apparatus was adjusted to place the subject in the proper testing position. Chest against the chest rest and the upper arm forming a right angle with the trunk, as the forearm rested on the table. The wrist cuff assembly was secured around the subject's wrist and a seat belt was secured around the subject's back. The subject was then ready for testing.

Isometric strength testing. The subject was readied for either extension or flexion isometric strength assessment, as previously described (page 69). The subject performed alternating fast maximum voluntary contractions (FMVC) and maximum voluntary contractions (MVC). On signal (ready pull or push), the subject exerted and maintained an MVC for five seconds followed by a one minute rest interval. The fast maximum voluntary contraction was held until a plateau was noted on the dynagraph recording. The subject was instructed to exert maximal efforts on all trials. Both the initial muscle group tested and the initial type of maximal contraction were alternated across testing sessions.

Speed testing. The subject was readied for maximum speed of forearm flexion as previously described on page 71. All clock counters and the storage oscilloscope were cleared prior to each trial. The signal given to each subject was "ready, go". On "ready", the drum mechanism of the Beckman dynagraph was engaged to the proper recording speed. On "go", the subject flexed his/her forearm to a target at 90 degrees as quickly as possible. Flexion triggered microswitches which initiated two clock counters and the storage oscilloscope. If any recording apparatus failed, a mis-trial was declared and the trial was repeated. At the end of each trial, all the measurements were recorded and the subject was instructed to return to the starting position.

Speed of movement trials were given in blocks of fifteen trials (see table 1). Resisted speed of movement trials differed only in the addition of a known mass to the wooden lever at the appropriate calculated distance.

Selection of subjects. The subjects for this investigation were selected from the undergraduate and graduate student body at the University of Massachusetts/Amherst. All the subjects were right-hand dominant. Medical clearance from the University Health Center was obtained for each subject and consent forms (Appendix C) were signed and witnessed in compliance with the Human Subjects Review Committee.

The determination of the adequate sample size for detection of meaningful differences was computed based on data obtained from previous related studies (54, 103).

TABLE 1

SCHEMATIC REPRESENTATION OF THE EXPERIMENTAL PROTOCOL

	DAYS	1	2	3	4	5	6	7	8	9	10
M.V.C.											
FLEXION (2)		x	x	x	x	x	x	x	x	x	x
EXTENSION (2)		x	x	x	x	x	x	x	x	x	x
F.M.V.C.											
FLEXION (2)		x	x	x	x	x	x	x	x	x	x
EXTENSION (2)		x	x	x	x	x	x	x	x	x	x
ELECTRODES		x	x	x	x	x	x	x	x	x	x
MAXIMUM SPEED OF MOVEMENT											
TRIALS	LOAD 0 (15)	x	x	x	x	x	x	x	x	x	x
	LOAD 1 (15)	x	x	x	x	x	x	x	x	x	x
	LOAD 2 (15)	x	x	x	x	x	x	x	x	x	x
FATIGUE											
FLEXION	5:5					x					
	5:10						x				
	5/5:0							x			
EXTENSION	5:5								x		
	5:10									x	
	5/5:0										x
POST FATIGUE											
F.M.V.C.											
FLEXION (1)						x	x	x	x	x	x
EXTENSION (1)						x	x	x	x	x	x
MAXIMUM SPEED OF MOVEMENT											
TRIALS	LOAD 0 (3)					x	x	x	x	x	x
	LOAD 1 (3)					x	x	x	x	x	x
	LOAD 2 (3)					x	x	x	x	x	x
END OF TEST											
F.M.V.C.											
FLEXION (1)						x	x	x	x	x	x
EXTENSION (1)						x	x	x	x	x	x

Experimental procedures. The total sample for this investigation was twelve men and twelve women, all right-hand dominant. Each subject reported to the Motor Integration Laboratory, University of Massachusetts/Amherst, for ten testing sessions. Each session was approximately 90 minutes in duration and occurred at time intervals which minimized diurnal effects (103). The first five testing days were consecutive, thereafter, a twenty-four hour rest interval could occur between the remaining five testing days.

The following variables were monitored during each testing session:

1. bioelectric activity from the biceps brachii and the triceps brachii;
2. maximum speed of forearm flexion
    a. unresisted (L0)
    b. resisted, two conditions (L1, L2);
3. acceleration time for forearm flexion;
4. maximum voluntary isometric elbow flexion strength
    a. fast maximum voluntary isometric elbow flexion strength; and
5. maximum voluntary isometric elbow extension strength
    a. fast maximum voluntary isometric elbow extension strength.

Baseline measures were recorded during each session for the following parameters:

1. movement time
2. biceps motor time
3. triceps motor time
4. time to zero acceleration
5. biceps to triceps latency
6. time to the second burst of the triceps muscle
7. MVC (isometric) elbow flexion
8. FMVC (isometric) elbow flexion
9. MVC (isometric) elbow extension
10. FMVC (isometric) elbow extension

All baseline measurements, with the exception of isometric strength assessments, were obtained during the three blocks of fifteen speed of movement trials. The first four testing sessions consisted of three blocks of speed of movement trials, one at each level of resistance. Maximum flexion and extension isometric strength were also assessed.

On the last six testing sessions, following baseline measurements, one of six fatigue regimens was imposed. Upon completion of the fatigue regimen, strength assessments (FMVC) and three trials at each resistance load were recorded. Prior to each block of three post fatigue speed of movement trials, the subject was re-fatigued (sustained MVC) to the level present at the end of the fatigue regimen. After the post fatigue speed of movement trial, FMVC flexion and extension were assessed. All conditions of fatigue and resistance were balanced across subject (see Table 2).

TABLE 2

ISOMETRIC FATIGUE MEASUREMENT SCHEDULE OVER 10 DAYS FOR ALL SUBJECTS, S1-S24.

FEMALES

DAYS	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
1	A021	B210	C102	D021	E210	F102	A021	C102	E210	D021	B210	F102
2	B102	C021	D210	E102	F021	A210	F201	B012	D120	C201	A120	E012
3	C210	D102	E021	F210	A102	B021	E120	A210	C012	B120	F012	D210
4	D012	E201	F120	A012	B201	C120	C210	E021	A102	F210	D102	B021
5	E120	F012	A201	B120	C012	D201	B102	D210	F021	E102	C021	A210
6	F201	A120	B012	C201	D120	E012	D012	F120	B201	A012	E201	C120

MALES

DAYS	S13	S14	S15	S1[illegible]	S17	S18	S19	S20	S21	S22	S23	S24
1	A021	B210	C102	D021	E210	F102	A021	C102	E210	D021	B210	F102
2	B102	C021	D210	E102	F021	A210	F201	B012	D120	C201	A120	E012
3	C210	D102	E021	F210	A102	B021	E120	A201	C012	B120	F012	D201
4	D012	E201	F120	A012	B201	C120	C210	E021	A102	F210	D102	B021
5	E120	F012	A201	B120	C012	D201	B102	D210	F021	E102	C021	A210
6	F201	A120	B012	C201	D120	E012	D012	F120	B201	A012	E201	C120

LEGEND:
A = 5:5 FLEXION
B = 5:10 EXTENSION
C = 5:5 EXTENSION
D = 5:10 FLEXION
E = 5/5:0 EXTENSION
F = 5/5:0 FLEXION

MOVEMENT RESISTANCE
0 = NO LOAD
1 = LOAD #1
2 = LOAD #2

ANALYSIS AND INTERPRETATION OF THE DATA

The data collected during this investigation was statistically analyzed in an attempt to answer the following questions.

1. What mechanisms, of those under investigation, were affected by the imposition of resistive loads?
2. Was the response to the isometric fatigue regimens identical across all resistive loads?
3. How was the maximum speed of forearm flexion affected by the fatigue regimens at each resistive load?
4. Were the treatment effects similar in kind and magnitude in both genders?
5. Was there a preferred order of variable selection which would enhance the prediction of maximum speed of forearm flexion? Was the order of selection altered by resistance conditions?

Physical data. The means, standard deviations, and the standard errors of the means were calculated for all the physical data.

Baseline conditions. The means, standard deviations, and intraclass correlation coefficients were calculated for all criterion measures collected under baseline conditions. Intraclass correlation coefficients were calculated as an indication of the reliability of the measures.

Baseline data for all criterion measures was analyzed statistically with the Split-split Plot Crossover design analysis of variance as shown in Table 3.

Treatment conditions. A schematic representation of the testing protocol for the treatment days is presented in Table 2. The six isometric treatment conditions were analyzed with the Graeco-Latin Square design analysis of variance (22). The treatment Graeco-Latin Square analysis, with the appropriate error terms for testing, is presented in Table 4. Orthogonal polynomial comparisons were computed, whenever appropriate.

A stepwise multiple regression analysis was applied across all variables under all conditions to ascertain the predictive power of each variable alone and in combination with other variables.

TABLE 3

ANALYSIS OF VARIANCE MODEL FOR THE BASELINE TREATMENT CONDITIONS OF RESISTIVE LOADING ACROSS TEN DAYS, N = 24.

Source		Degrees of Freedom
Whole Plot	23	
Groups (G)		1
Block w/groups (B:G)		2
Subjects w/blocks (S:BG)		20
Split Plot	120	
Days (D)		5
DG		5
DB:G		10
DS:BG		100
Split-split	288	
Loads (L)		2
GL		2
BL:G		4
SL:BG		40
DL		10
LDG		10
BDL:G		20
Error		200
TOTAL		431

TABLE 4

ANALYSIS OF VARIANCE FOR ALL TREATMENT CONDITIONS OF ISOMETRIC EXERCISE ACROSS SIX DAYS, N = 24.

Source	Degrees of Freedom	F Ratio
Groups (G)	1	G/B:G
Blocks w/groups (B:G)	2	B:G/S:BG
Subjects w/blocks (S:BG)	20	S:BG/error
Days (D)	5	D/BD:G
Regimens (R)	5	R/BR:G
Loads (L)	2	L/BL:G
Load Order (O)	2	O/BO:G
GD	5	GD/BD:G
GR	5	GR/BR:G
GL	2	GL/BL:G
GO	2	GO/BO:G
BD:G	10	BD:G/error
BR:G	10	BR:G/error
BL:G	4	BL:G/error
BO:G	4	BO:G/error
Error	352	
TOTAL	431	

Note: Groups, days, regimens, and loads are considered fixed effects. Blocks and subjects are considered random effects.

Summary

The experimental protocol employed in this investigation called for the testing of twenty-four subjects, twelve men and twelve women. Baseline data was collected for ten days, under three inertial loads conditions, on the following criterions measures:

1. movement time to maximal displacement;
2. biceps motor time;
3. triceps motor time;
4. time to zero acceleration;
5. biceps to triceps latency;
6. time to the second burst of the triceps;
7. isometric FMVC and MVC elbow flexion; and
8. isometric FMVC and MVC elbow extension.

On the last six days, after baseline data collection, one of six isometric fatigue regimens was imposed. Averaged electromyographic activity was recorded from the biceps brachii and the triceps brachii of the right arm for all the subjects.

The baseline data was analyzed for reliability by the intraclass correlation analysis of variance technique. The baseline data was analyzed for stability by the Repeated Measures design analysis of variance.

The six isometric treatment conditions were analyzed

with the Graeco-Latin Square design analysis of variance. A stepwise multiple regression analysis was applied across all variables, under all conditions, to ascertain the predictive power of each variable alone and in combination with other variables. Means, standard deviations, standard errors, and ranges were calculated for all criterion measures.

ANALYSIS OF THE DATA

Introduction

The analysis will be presented in the following sections:

1. physical characteristics;
2. analysis of the baseline conditions; and
3. analysis of the experimental conditions.

Between groups data were scrutinized to verify the existence or non-existence of gender specific differences. An alpha risk level of .05 was declared prior to experimentation. In addition, the interrelationships among all the criterion measures were explored.

Physical Characteristics of the Subjects

The physical characteristics of the twelve women and twelve men, who volunteered to serve as subjects for the present investigation, are presented in Table 5. Mean values, pooled over the four practice days, are reported. The subject sample included graduate and undergraduate students, at the University of Massachusetts, with a mean age of 22.9 years. Though athletically oriented students

TABLE 5

PHYSICAL CHARACTERISTICS OF THE SUBJECTS, N = 24.

	MEAN $\bar{X}$	STANDARD DEVIATION S.D.	STANDARD ERROR S.E.
AGE COMBINED (years)	22.95	4.25	.87
FEMALE	23.53	4.67	1.35
MALE	22.36	3.89	1.12
WEIGHT COMBINED (kg.)	69.98	8.89	1.81
FEMALE	65.55	7.93	2.29
MALE	74.41	7.71	2.23
FLEXION STRENGTH COMBINED (lbs.)	38.67	13.30	2.71
FEMALE	27.16	5.88	1.70
MALE	50.19	6.80	1.96
EXTENSION STRENGTH COMBINED (lbs.)	31.35	8.28	1.69
FEMALE	27.40	8.53	2.46
MALE	35.31	6.03	1.74
LENGTH OF FOREARM COMBINED (cm.)	26.52	1.85	.38
FEMALE	25.13	1.06	.31
MALE	27.92	1.35	.39

were not actively selected, these subjects should be considered well above average in their level of physical activity. The male subjects' characteristics approximated those of Lagasse's (54) and Wolcott's (103) subject sample, that is, male, right hand dominant, undergraduate and graduate students.

Analysis of Baseline Conditions

Measurement protocol effects and reliability assessments

Baseline measures were collected on each of the ten testing days. On experimental days 5 though 10, when one of six fatigue regimens was imposed, baseline measures were collected immediately prior to the imposition of the fatigue regimen. On each day, ten speed of movement trials were performed under each inertial load condition. Load 0 was equal to .9 times the natural moment of inertia about the elbow joint. Load 1 was three (3) times the natural moment of inertia. Load 2 was seven (7) times the natural moment of inertia. The criterion measures for movement time to maximal displacement were: movement time, acceleration time, time to maximal acceleration, first biceps motor time, first biceps duration, first triceps motor time, second triceps motor time, second triceps duration, first biceps burst to first triceps burst latency, first biceps burst to second triceps burst latency, second triceps burst to zero acceleration latency, second triceps burst to maximal acceleration latency, maximal displacement, accuracy, slope of the EMG for the first biceps burst, slope of the EMG for the second triceps burst, ratio between first biceps EMG and second triceps EMG, and ratio between total biceps EMG and total triceps EMG. The criterion measures for the first ninety degrees of forearm flexion were: movement time, acceleration time, time to second biceps burst, and time to second triceps burst.

The stability of all baseline measures both across and within days was paramount to the present investigation, since the experimental effects were analyzed in comparison to the baseline measures. Significant variance associated with a days effect would confound a condition effect, while significant inconsistency within days would confound the pre and post fatigue treatment effects. In accordance with previous investigations (54, 103), which employed similar testing apparatus, four days of practice were affored the subjects to insure the stabilization of the criterion measures. The mean values for 10 trials for day 1 and days 4 through 10 for each criterion measure, under each inertial load condition, are presented in Tables 6, 7, and 8. On practice days 3 and 4, data was collected solely from the two clock counters, which recorded movement time for the first ninety degrees of flexion and the time to zero acceleration over the first ninety degrees of flexion. The

TABLE 6

MEAN VALUES OF 10 TRIALS FOR THE CRITERION MEASURES UNDER LOAD CONDITION 0, N = 24.*

MEASURES	DAYS							
MEN	1	4	5	6	7	8	9	10
MOVEMENT TIME	192.7	179.2	179.0	180.0	178.4	180.0	181.0	177.0
ACCELERATION TIME	134.0	134.2	139.2	139.1	137.0	138.3	142.6	136.7
TIME TO MAXIMAL ACCELERATION	73.3	74.9	80.2	78.9	79.3	78.0	82.6	78.3
BICEPS MOTOR TIME (1-B)**	69.8	-62.3	-6 .2	-61.1	-60.2	-60.9	-62.6	-63.1
BICEPS (1-B) DURATION	124.9	110.3	114.7	118.3	116.7	120.4	122.4	122.7
BICEPS SILENT PERIOD	105.3	139.8	118.7	112.1	112.9	113.5	127.9	115.1
TRICEPS MOTOR TIME (1-B)**	-69.6	-59.8	-42.7	-42.4	-41.8	-43.5	-46.0	-42.1
TRICEPS MOTOR TIME (2-B)	109.5	99.4	95.5	97.5	98.2	99.8	94.1	90.1
TRICEPS (2-B) DURATION	86.1	81.6	85.9	78.0	82.3	88.3	83.9	71.2
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	17.7	27.6	27.5	26.3	21.1	24.3	25.1	28.1
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	140.5	136.9	139.9	140.0	136.4	137.5	144.9	144.6
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	-1.6	-4.9	-3.3	-2.8	-.7	-2.1	-4.4	-8.5
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	59.1	54.4	55.8	56.4	56.8	58.3	55.6	50.0
MAXIMAL DISPLACEMENT	100.9	100.5	102.1	101.8	99.5	103.6	102.3	101.9
SLOPE FOR BICEPS(1B) EMG	1.3	1.2	1.2	1.3	1.3	1.1	1.3	1.2
SLOPE FOR TRICEPS(2B) EMG	2.6	2.7	1.7	1.4	1.7	1.6	1.4	1.6
BICEPS(1B)/TRICEPS(2B) EMG	42.3	34.5	42.8	44.3	40.9	42.9	38.6	36.8
BICEPS EMG/TRICEPS EMG	4.0	3.9	3.2	3.4	3.2	3.6	3.0	3.2

TABLE 6 (con't.)

MEASURES WOMEN	DAYS 1	4	5	6	7	8	9	10
MOVEMENT TIME	228.5	195.4	200.0	205.4	205.7	201.5	207.2	200.5
ACCELERATION TIME	152.4	148.5	149.3	152.7	154.4	153.3	151.4	152.0
TIME TO MAXIMAL ACCELERATION	76.4	70.3	72.1	75.4	77.7	79.6	80.3	79.5
BICEPS MOTOR TIME (1-B)**	-73.7	-72.4	-73.9	-71.7	-73.0	-68.5	-69.4	-73.0
BICEPS (1-B) DURATION	148.5	144.0	137.2	134.1	133.8	132.5	129.8	136.6
BICEPS SILENT PERIOD	118.1	145.2	156.5	161.0	154.1	155.5	155.9	159.5
TRICEPS MOTOR TIME (1-B)**	-63.8	-58.2	-55.2	-60.4	-57.7	-50.2	-48.1	-58.5
TRICEPS MOTOR TIME (2-B)	116.7	104.9	109.6	114.7	110.2	109.9	109.8	103.7
TRICEPS (2-B) DURATION	94.8	71.9	81.6	85.7	84.7	84.0	82.9	79.0
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	13.7	18.6	21.0	14.1	16.1	15.7	19.2	7.6
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	158.0	162.7	163.1	157.4	164.2	156.3	162.4	165.3
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	-22.2	-20.3	-18.3	-15.4	-17.7	-12.0	-17.1	-17.3
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	48.9	58.0	59.0	62.0	58.9	61.7	53.9	55.2
MAXIMAL DISPLACEMENT	104.2	107.5	105.2	107.9	106.4	106.5	109.1	108.3
SLOPE FOR BICEPS(1B) EMG	4.4	4.1	3.9	3.4	3.4	3.6	3.2	3.9
SLOPE FOR TRICEPS(2B) EMG	5.2	4.2	5.1	5.7	5.1	5.0	6.5	5.6
BICEPS(1B)/TRICEPS(2B) EMG	35.1	32.6	39.8	41.3	48.3	40.6	48.7	32.3
BICEPS EMG/TRICEPS EMG	5.2	4.5	4.1	4.6	5.1	4.3	5.5	4.6

*Maximal Displacement is expressed in degrees, all other measures are expressed in milliseconds.

** Negative values indicate time prior to the initiation of movement.

TABLE 7

MEAN VALUES OF 10 TRIALS FOR THE CRITERION MEASURES UNDER LOAD CONDITION 1, N = 24.*

MEASURES	DAYS							
MEN	1	4	5	6	7	8	9	10
MOVEMENT TIME	207.5	193.2	193.4	187.8	192.2	191.5	186.1	192.4
ACCELERATION TIME	137.6	139.1	142.7	140.6	142.5	141.7	140.3	143.2
TIME TO MAXIMAL ACCLERATION	64.1	71.6	71.9	72.3	70.3	72.9	71.8	73.9
BICEPS MOTOR TIME (1-B)**	-82.6	-72.7	-73.7	-77.2	-72.1	-70.6	-77.4	-75.5
BICEPS (1-B) DURATION	126.8	122.5	135.5	135.3	134.5	130.2	132.0	126.2
BICEPS SILENT PERIOD	109.7	123.2	108.0	110.8	102.0	110.0	116.1	122.0
TRICEPS MOTOR TIME (1-B)**	-77.7	-64.3	-61.5	-57.2	-45.8	-54.2	-56.3	-49.9
TRICEPS MOTOR TIME (2-B)	145.8	116.5	111.8	116.5	111.8	110.1	109.2	112.5
TRICEP (2-B) DURATION	90.2	72.6	78.0	83.3	82.1	83.5	85.9	80.2
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	4.8	8.4	12.2	19.9	26.3	16.4	21.1	25.6
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	139.8	145.7	152.5	144.3	149.8	148.0	151.0	152.2
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	2.4	-5.2	-9.8	1.0	-10.0	-8.5	-5.0	-6.1
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	75.9	62.4	61.1	69.3	62.2	60.2	63.6	63.3
MAXIMAL DISPLACEMENT	101.6	102.2	106.2	104.5	102.0	103.0	103.8	105.3
SLOPE FOR BICEPS(1B) EMG	1.3	1.4	1.4	1.3	1.5	1.4	1.3	1.3
SLOPE FOR TRICEPS(2B) EMG	7.2	3.3	2.3	3.8	3.4	2.5	2.2	2.4
BICEPS(1B)/TRICEPS(2B) EMG	168.5	56.3	56.2	64.1	65.3	64.6	71.8	67.3
BICEPS EMG/TRICEPS EMG	9.2	5.6	3.9	4.8	4.0	4.2	4.5	4.2

TABLE 7 (con't.)

MEASURES WOMEN	DAYS 1	4	5	6	7	8	9	10
MOVEMENT TIME	248.0	231.7	226.7	228.9	234.0	232.4	231.5	230.9
ACCELERATION TIME	168.0	168.0	162.4	161.0	168.8	166.3	167.7	167.1
TIME TO MAXIMAL ACCELERATION	81.6	79.9	78.8	82.9	87.4	84.6	80.3	77.8
BICEPS MOTOR TIME (1-B)**	-88.0	-87.1	-85.8	-84.2	-80.0	-80.1	-78.3	-81.2
BICEPS (1-B) DURATION	164.4	168.2	161.7	154.2	158.4	153.1	157.9	159.7
BICEPS SILENT PERIOD	115.0	135.0	145.0	140.1	141.0	143.7	142.7	144.1
TRICEPS MOTOR TIME (1-B)**	-81.9	-69.7	-68.4	-77.9	-71.9	-74.2	-76.4	-73.1
TRICEPS MOTOR TIME (2-B)	156.5	129.4	137.0	141.6	142.9	135.4	137.9	131.4
TRICEPS (2-B) DURATION	101.4	94.3	108.3	117.2	116.1	102.9	112.7	103.5
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	6.1	17.7	17.4	0.9	8.0	5.9	1.9	8.0
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	174.9	187.2	173.2	168.8	168.2	174.9	169.8	177.7
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	-9.9	-22.3	-10.9	-4.4	-3.6	-12.3	-13.2	-21.6
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	76.4	65.8	72.7	73.7	77.8	69.3	74.1	67.7
MAXIMAL DISPLACEMENT	104.6	109.4	108.2	107.5	106.1	109.2	105.6	108.1
SLOPE FOR BICEPS(1B) EMG	5.7	7.3	4.3	3.9	4.0	4.2	4.1	4.4
SLOPE FOR TRICEPS(2B) EMG	17.8	7.8	9.6	9.6	10.6	7.3	12.2	7.1
BICEPS(1B)/TRICEPS(2B)	56.5	49.8	54.9	57.8	57.6	67.5	54.3	58.3
BICEPS EMG/TRICEPS EMG	11.1	5.0	6.3	4.1	7.7	4.3	6.9	4.5

*Maximal Displacement is expressed in degrees, all other measures are expressed in milliseconds.

**Negative values indicate time prior to the initiation of movement.

TABLE 8

MEAN VALUES OF 10 TRIALS FOR THE CRITERION MEASURES UNDER LOAD CONDITION 2, N = 24.*

MEASURES / MEN	DAYS 1	4	5	6	7	8	9	10
MOVEMENT TIME	237.9	229.8	227.1	224.1	223.7	223.6	226.8	232.7
ACCELERATION TIME	162.3	161.5	164.3	162.9	163.9	162.5	166.0	169.5
TIME TO MAXIMAL ACCELERATION	61.5	67.0	65.9	70.2	66.9	68.7	72.3	72.6
BICEPS MOTOR TIME (1-B)**	-95.9	-87.7	-86.1	-84.2	-86.3	-86.8	-87.9	-8[illegible].6
BICEPS (1-B) DURATION	144.9	136.9	140.2	137.4	145.2	140.0	144.1	140.9
BICEPS SILENT PERIOD	154.5	160.4	154.3	148.5	150.5	145.5	151.6	159.8
TRICEPS MOTOR TIME (1-B)**	-88.1	-68.8	-66.0	-65.4	-65.2	-70.4	-67.8	-70.1
TRICEPS MOTOR TIME (2-B)	154.6	149.1	131.7	139.0	139.7	136.5	135.3	142.1
TRICEPS (2-B) DURATION	95.5	83.0	84.1	91.4	93.3	94.3	95.8	100.2
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	21.4	40.7	46.0	32.5	21.0	29.1	27.6	28.0
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	172.7	166.2	179.4	165.4	168.3	171.4	176.6	172.7
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	-21.8	-13.7	-29.5	-15.0	-17.1	-18.4	-19.1	-18.0
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	79.0	80.9	68.9	77.8	90.0	75.4	74.5	78.9
MAXIMAL DISPLACEMENT	104.8	104.1	104.9	105.0	102.6	102.3	104.3	107.9
SLOPE FOR BICEPS(1B) EMG	1.4	1.7	1.5	1.3	1.5	1.6	1.6	1.4
SLOPE FOR TRICEPS(2B) EMG	6.1	4.3	2.6	3.6	5.1	3.3	3.0	3.1
BICEPS(1B)/TRICEPS(2B) EMG	81.4	60.7	78.6	57.7	84.7	50.7	46.3	84.8
BICEPS EMG/TRICEPS EMG	11.6	5.4	4.6	4.7	4.8	4.2	4.7	3.9

TABLE 8 (con't.)

MEASURES WOMEN	DAYS 1	4	5	6	7	8	9	10
MOVEMENT TIME	287.6	271.7	271.6	269.6	280.3	276.5	272.0	275.1
ACCELERATION TIME	194.0	193.3	193.7	188.2	196.5	198.1	193.5	194.8
TIME TO MAXIMAL ACCELERATION	80.7	82.7	90.8	89.5	93.4	100.4	81.3	89.7
BICEPS MOTOR TIME (1-B)**	-100.4	-107.3	-101.9	-105.6	-105.3	-99.5	-102.7	-100.1
BICEPS (1-B) DURATION	170.5	182.6	177.4	169.8	186.4	179.2	182.1	183.7
BICEPS SILENT PERIOD	148.3	150.5	158.0	156.5	150.7	157.0	150.7	143.7
TRICEPS MOTOR TIME (1-B)**	-85.8	-84.9	-83.1	-88.6	-80.7	-84.8	-80.3	-80.7
TRICEPS MOTOR TIME (2-B)	165.9	152.8	152.2	159.8	156.9	155.3	152.6	153.9
TRICEPS (2-B) DURATION	116.0	109.1	119.6	119.5	112.8	107.9	118.8	122.2
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	13.6	15.8	18.8	12.8	15.2	14.7	23.9	10.4
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	219.0	225.2	219.8	214.0	226.8	219.4	220.5	218.0
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	-41.1	-36.3	-28.6	-20.3	-30.0	-20.8	-38.1	-30.5
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	72.2	74.4	74.2	78.4	73.2	76.9	74.2	74.6
MAXIMAL DISPLACEMENT	104.5	109.8	109.2	105.9	106.1	108.9	106.8	108.8
SLOPE FOR BICEPS(1B) EMG	4.4	4.0	3.8	4.1	4.5	4.4	4.1	4.8
SLOPE FOR TRICEPS(2B) EMG	16.8	8.0	8.3	9.7	10.1	8.4	9.5	8.9
BICEPS(1B)/TRICEPS(2B) EMG	43.9	73.5	58.5	53.5	62.5	66.6	75.2	76.7
BICEPS EMG/TRICEPS EMG	14.6	6.0	5.8	6.1	7.3	6.4	7.4	5.0

*Maximal Displacement is expressed in degrees, all other measures are expressed in milliseconds.

**Negative values indicate time prior to the initiation of movement.

time to the second burst of activity from both the biceps and triceps brachii was captured on the storage oscilloscope. The mean values for 10 trials for day 1 through day 10 are presented in Table 9.

Movement time

Significant decreases in movement time occurred over the four practice days as shown in Tables 6, 7, and 8. The men were consistantly faster than the women across all load conditions. As the inertial load increased the magnitude of the difference between genders also increased. The magnitude of the differences between genders diminished when the movement times over the first ninety degrees of flexion, presented in Table 9, were compared. Figures 3 and 4 illustrate the small, 10 msec. or less, fluctuation in movement time to maximal displacement and movement time for the first ninety degrees of flexion, after day 4, for both men and women, under all load conditions.

Acceleration time

Mean values for acceleration time presented in Tables 6, 7, 8, and 9 failed to reveal a discernible pattern of change across days 1 to 10, for both men and women, under all load conditions, for acceleration time over the first ninety degrees of flexion, and acceleration time to maximal displacement. However, as movement time decreased over days 1 to 10, the subjects must have accelerated over a longer percentage of the movement. Figures 5 and 6 graphically

TABLE 9

MEAN VALUES OF 10 TRIALS FOR THE CRITERION MEASURES DURING THE FIRST NINETY DEGREES OF FOREARM FLEXION UNDER ALL LOAD CONDITIONS, N = 24.*

MEN	DAYS									
LOAD 0	1	2	3	4	5	6	7	8	9	10
MOVEMENT TIME (90°)	135.5	133.1	135.4	131.5	126.5	129.4	127.9	126.7	128.7	127.6
ACCELERATION TIME	120.2	123.7	127.0	125.6	118.7	121.6	122.2	121.8	121.0	123.0
TIME TO 2ND BICEPS BURST	118.0	150.3	144.0	141.2	140.7	142.2	133.1	142.4	139.1	137.3
TIME TO 2ND TRICEPS BURST	59.4	69.4	60.9	62.6	62.1	65.4	62.3	65.4	62.8	63.2
LOAD 1										
MOVEMENT TIME (90°)	151.0	144.9	148.8	141.6	137.5	140.4	141.6	140.6	137.9	139.7
ACCELERATION TIME	136.9	133.9	134.2	131.9	126.5	131.2	130.8	130.2	129.8	129.3
TIME TO 2ND BICEPS BURST	132.8	155.5	149.5	146.7	139.3	144.9	141.3	152.7	149.6	150.4
TIME TO 2ND TRICEPS BURST	69.8	70.7	62.3	61.8	62.3	66.2	64.4	67.0	63.7	64.5
LOAD 2										
MOVEMENT TIME (90°)	171.0	169.7	170.8	170.6	168.7	172.1	170.3	170.3	168.9	167.3
ACCELERATION TIME	148.9	152.5	151.4	149.9	146.6	148.7	148.7	149.4	149.8	148.7
TIME TO 2ND BICEPS BURST	163.6	184.6	175.5	179.6	175.3	172.7	166.1	176.4	172.1	176.6
TIME TO 2ND TRICEPS BURST	83.5	88.4	77.8	79.6	76.6	80.8	80.2	82.1	78.6	81.3

TABLE 9 (con't.)

WOMEN	DAYS									
	1	2	3	4	5	6	7	8	9	10
LOAD 0										
MOVEMENT TIME (90°)	162.2	151.7	147.6	143.0	144.4	146.5	144.2	140.9	139.7	139.0
ACCELERATION TIME	132.9	135.2	136.8	131.6	134.8	133.4	132.7	127.8	130.3	128.1
TIME TO 2ND BICEPS BURST	139.0	154.9	152.7	169.7	169.2	178.9	172.0	172.5	169.7	177.7
TIME TO 2ND TRICEPS BURST	80.0	81.9	84.2	76.0	77.5	74.9	76.4	76.3	71.9	75.9
LOAD 1										
MOVEMENT TIME (90°)	178.2	169.9	165.0	163.6	164.2	164.1	161.9	157.8	156.9	156.7
ACCELERATION TIME	142.0	143.3	145.7	140.3	145.2	145.1	144.6	141.8	142.0	142.4
TIME TO 2ND BICEPS BURST	157.0	178.3	179.8	186.7	198.8	195.9	191.6	191.0	194.5	191.8
TIME TO 2ND TRICEPS BURST	82.5	85.3	91.0	86.5	87.6	83.6	85.4	81.6	78.8	81.9
LOAD 2										
MOVEMENT TIME (90°)	215.1	206.2	202.1	202.8	199.7	201.2	197.2	195.4	197.3	195.6
ACCELERATION TIME	155.3	162.2	165.7	162.4	163.2	165.5	163.6	165.0	164.1	168.6
TIME TO 2ND BICEPS BURST	183.8	209.3	217.0	234.2	240.6	233.5	227.0	234.1	250.7	241.6
TIME TO 2ND TRICEPS BURST	113.2	114.0	115.9	111.3	112.4	105.3	105.4	104.6	106.2	109.4

*All measures are expressed in milliseconds.

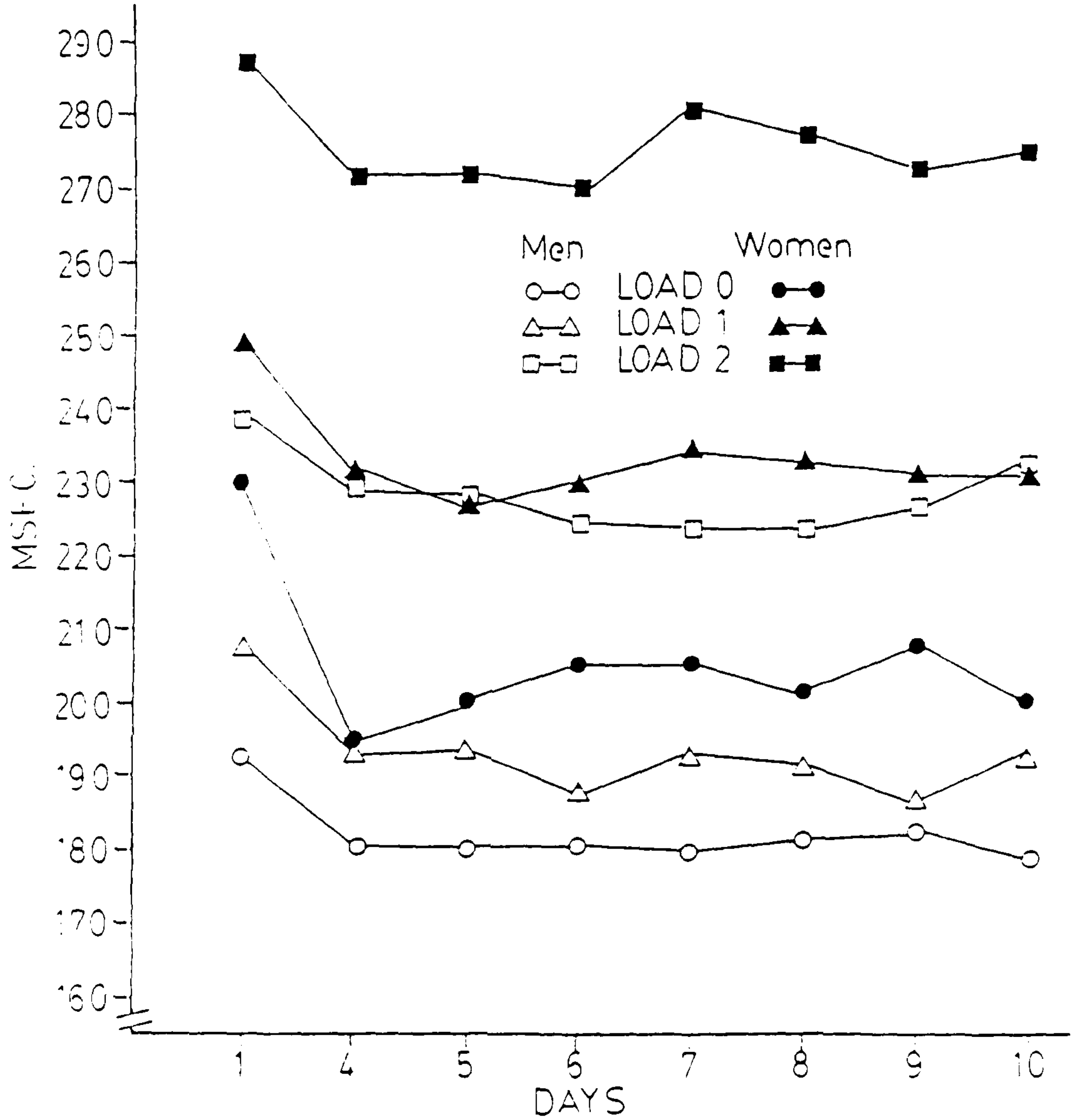


Fig. 3. Means for Movement Time Across Days 1-15, under all Load Conditions, N = 24.

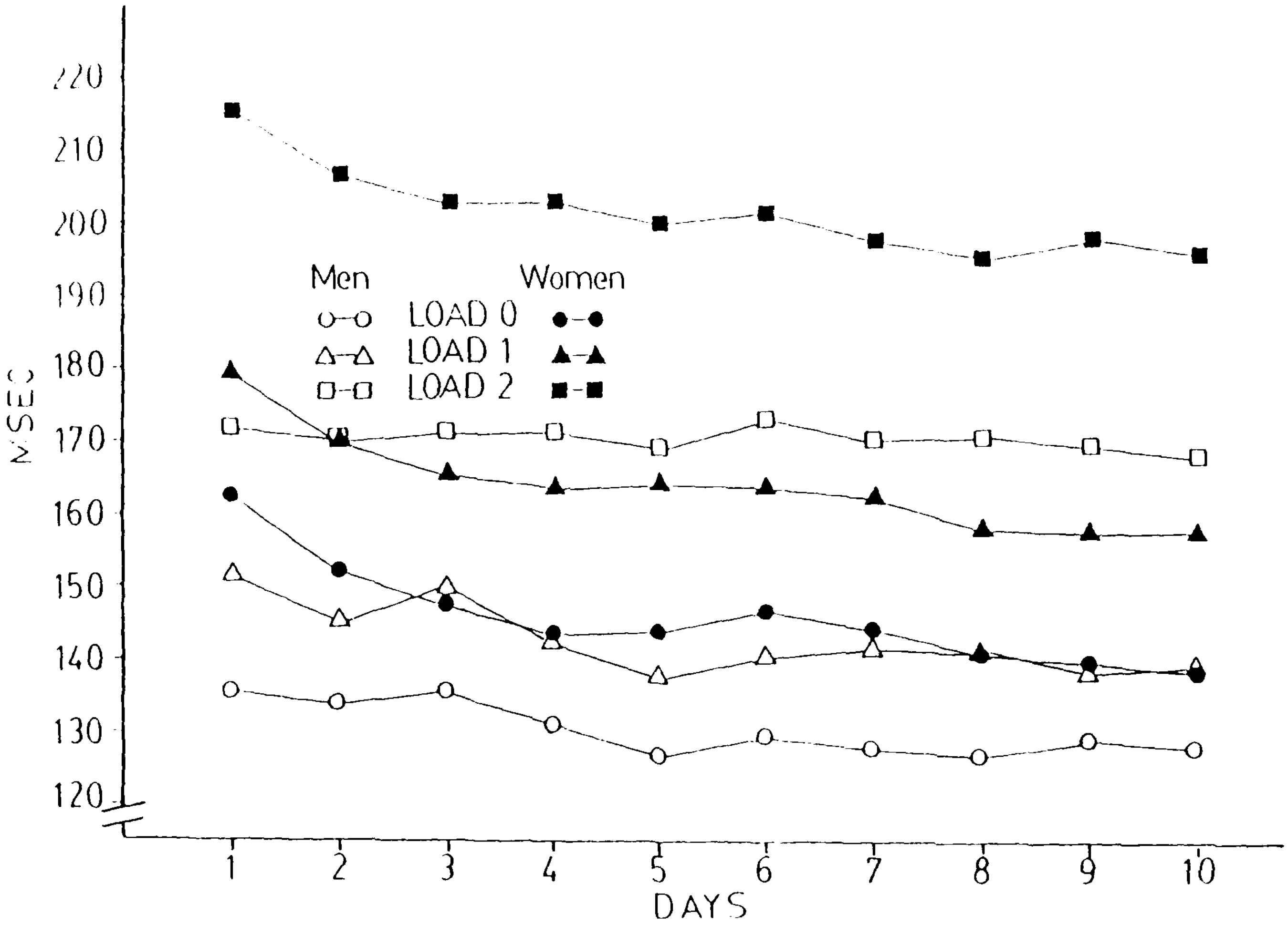


Fig. 4. Means for Movement Time Across Days 1-15 for the First Ninety Degrees of Flexion, under all Load Conditions, N = 24.

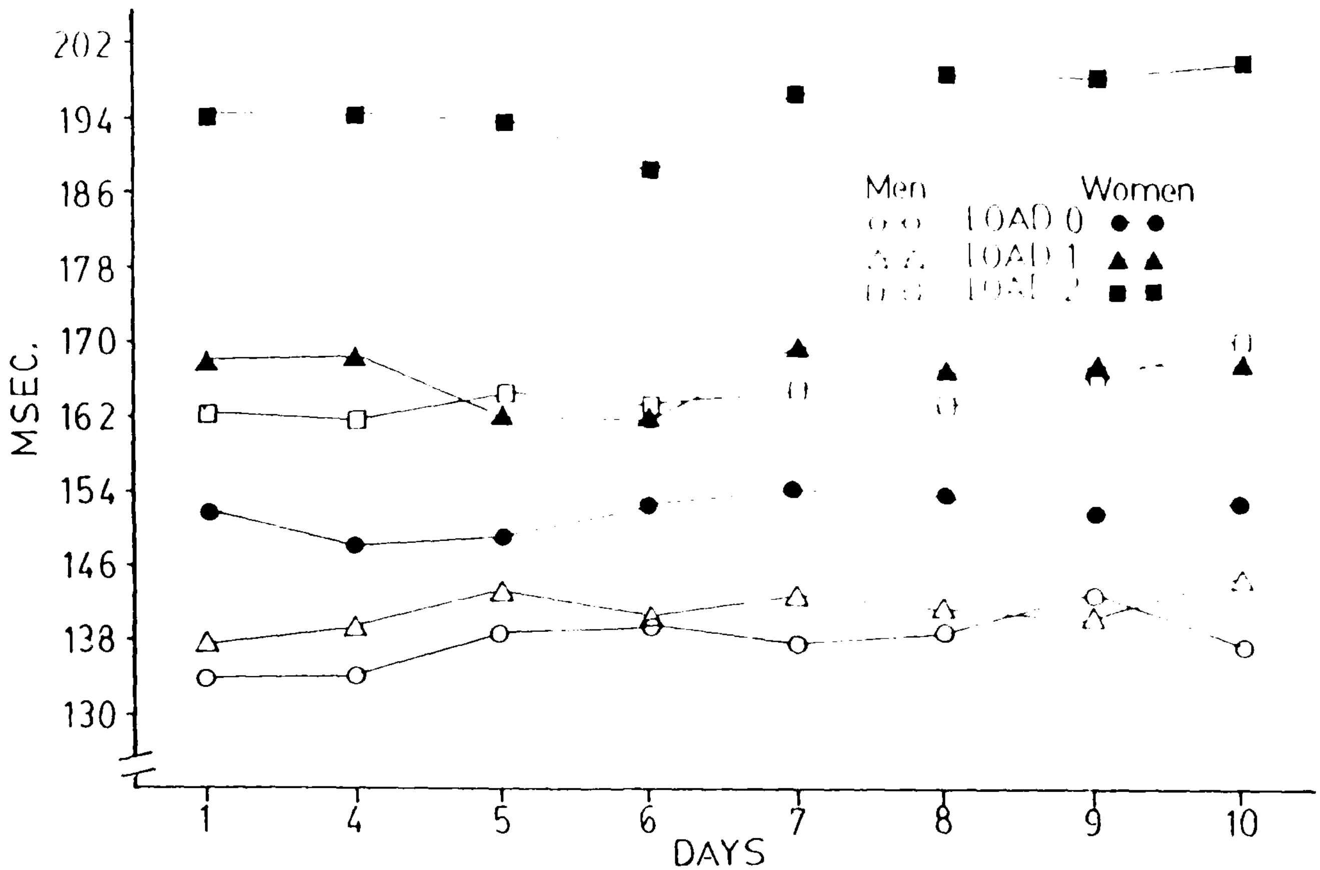


Fig. 5. Means for Acceleration Time across Days 1-15, under all Load Conditions, N = 24.

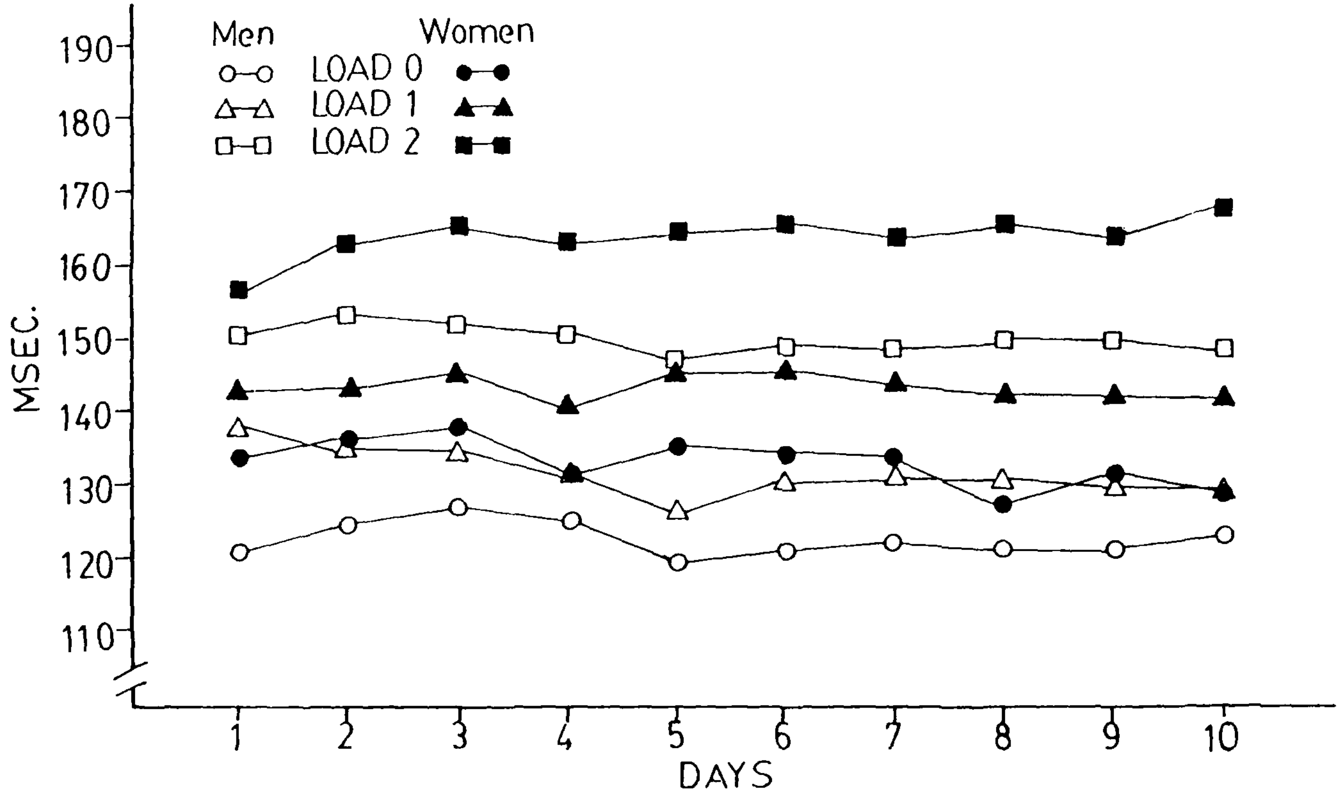


Fig. 6. Means for Acceleration Time across Days 1-15 for the first ninety degrees of flexion, under all Load Conditions, N = 24.

illustrate the pattern of the acceleration time means.

Time to maximal acceleration

Figure 7 graphically depicts the daily means presented in Tables 6, 7, and 8. This acceleration parameter revealed a different mechanism of execution for the women versus the men. The women increased the time to maximal acceleration as the inertial load increased. While the men decreased the time to maximal acceleration as the inertial load increased. Although the patterns indicated an extreme narrowing of the range for the time to maximal acceleration among inertial loads for both men and women, Load 0 for the men and Load 2 for the women produced the longest times to maximal acceleration.

First biceps motor time

Inspection of Tables 6, 7, and 8 revealed a pattern in the means for the men, over day 1 to day 4, the first biceps burst occurred later and nearer the onset of movement. The slope of the decrease was seemingly unaffected by inertial loading, Thereafter, as illustrated in Figure 8, the fluctuation was 4 msec. or less under all load conditions. The women did not exhibit a similar pattern of change. As graphically depicted in Figure 8, the pattern revealed a later occurrence of the first biceps burst, however, under Loads 0 and 1, stabilization occurred after day 5 or later. Under Load 2, the pattern is totally dissimilar, biceps motor time occurred earlier and, therefore, farther from the onset of

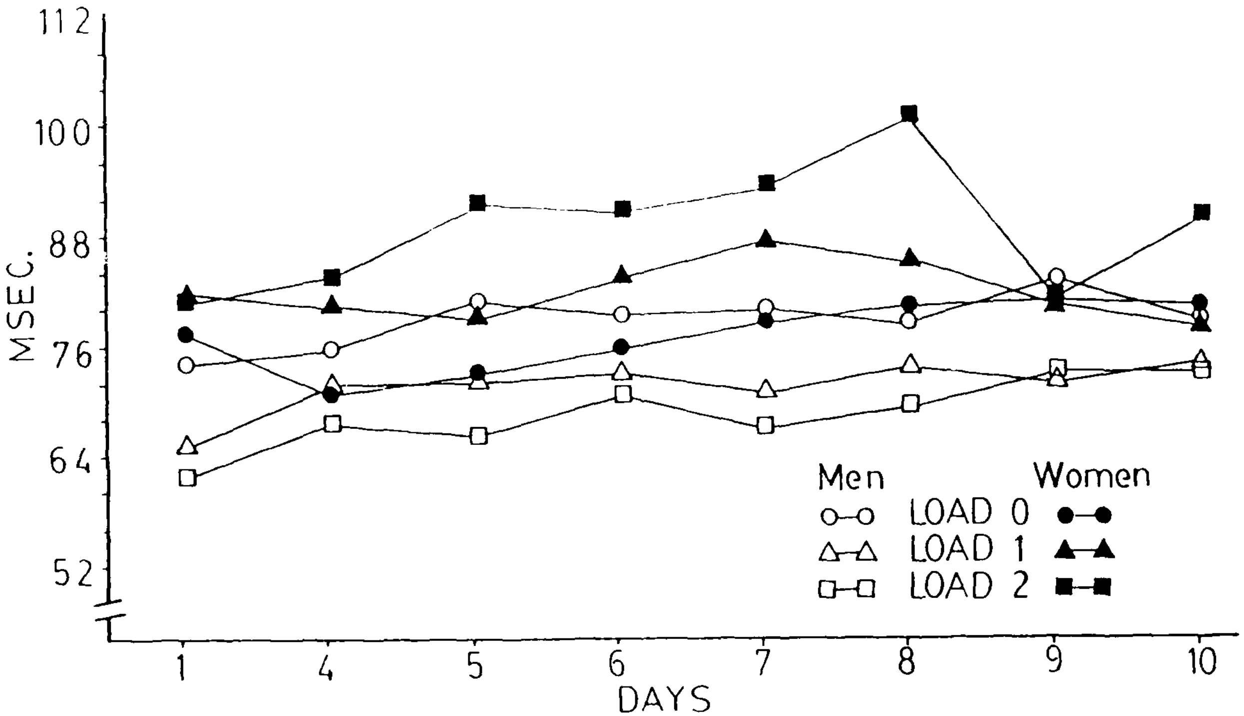


Fig. . Means for Time to Maximal Acceleration across Days 1-15, under all Load Conditions, N = 24.

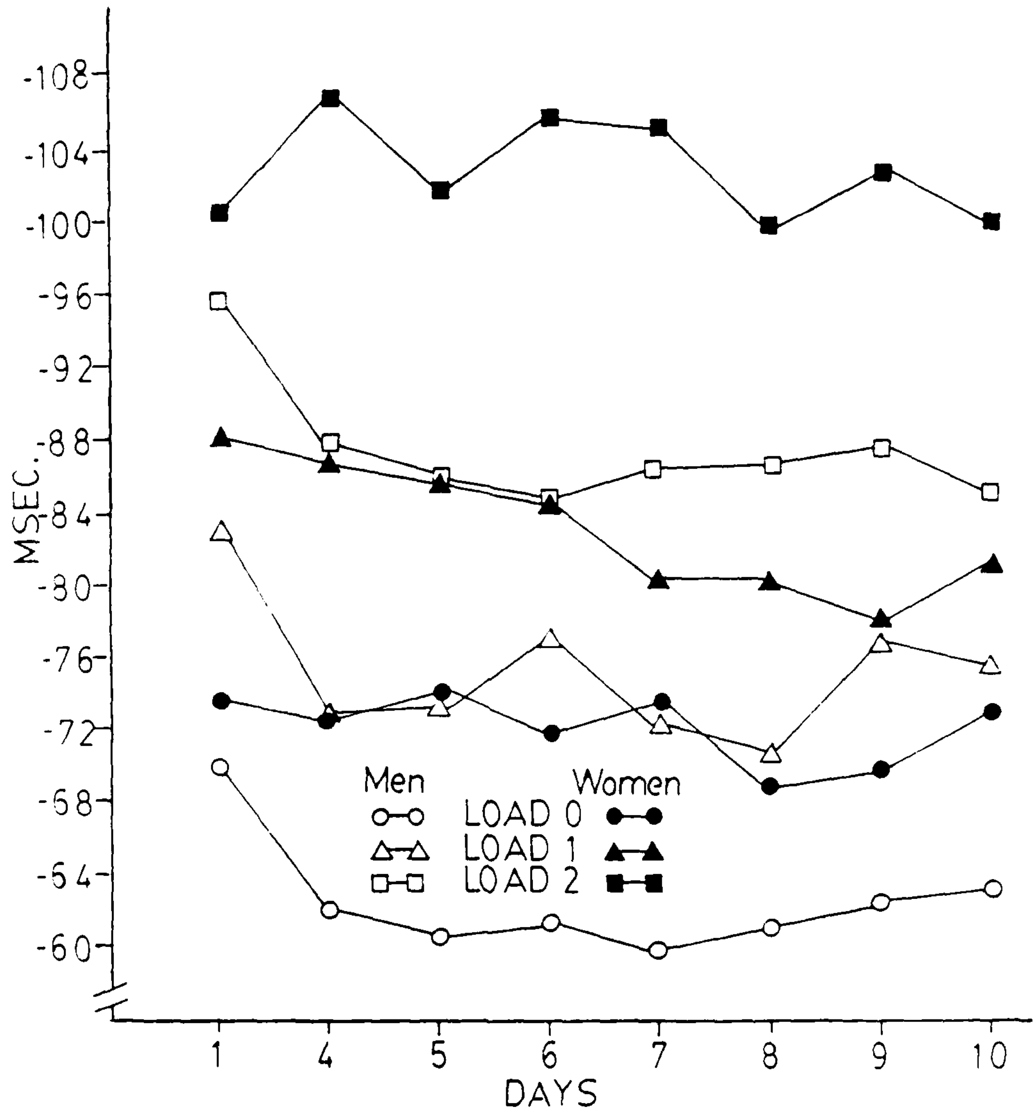


Fig. . Means for First Biceps Motor Time across Days 1-15, under all Load Conditions, N = 24.

movement. The magnitude of the inertial load may have been influential.

First biceps duration

Daily means for first biceps duration are presented in Tables 6, 7, and 8. They are graphically depicted in Figure 9. The duration of the first biceps burst increased as the inertial load increased, within each load condition, except for women Load 2, decreases in duration were evident. The duration of the first biceps in the women more pronouncely reflected the influence of inertial loading.

First triceps motor time

Figure 10 graphically illustrates the pattern of change manifested by the first triceps motor time. The daily means are presented in Tables 6, 7, and 8. The pattern was one dramatic shifts towards the onset of movement for all subjects under all load conditions, with the exception of women, under Load Condition 2, which produced a similar but more modest shift. Stabilization, except for women Load 2, occurred at day 5 or later.

Second triceps motor time

The second triceps motor time daily means are presented in Tables 6, 7, and 8. Figure 11 revealed a marked decrease in the second triceps motor time for all subjects under all load conditions. The slope of the change increased as the inertial load increased. Stabilization, particularly for the men, extended into day five. The second triceps motor

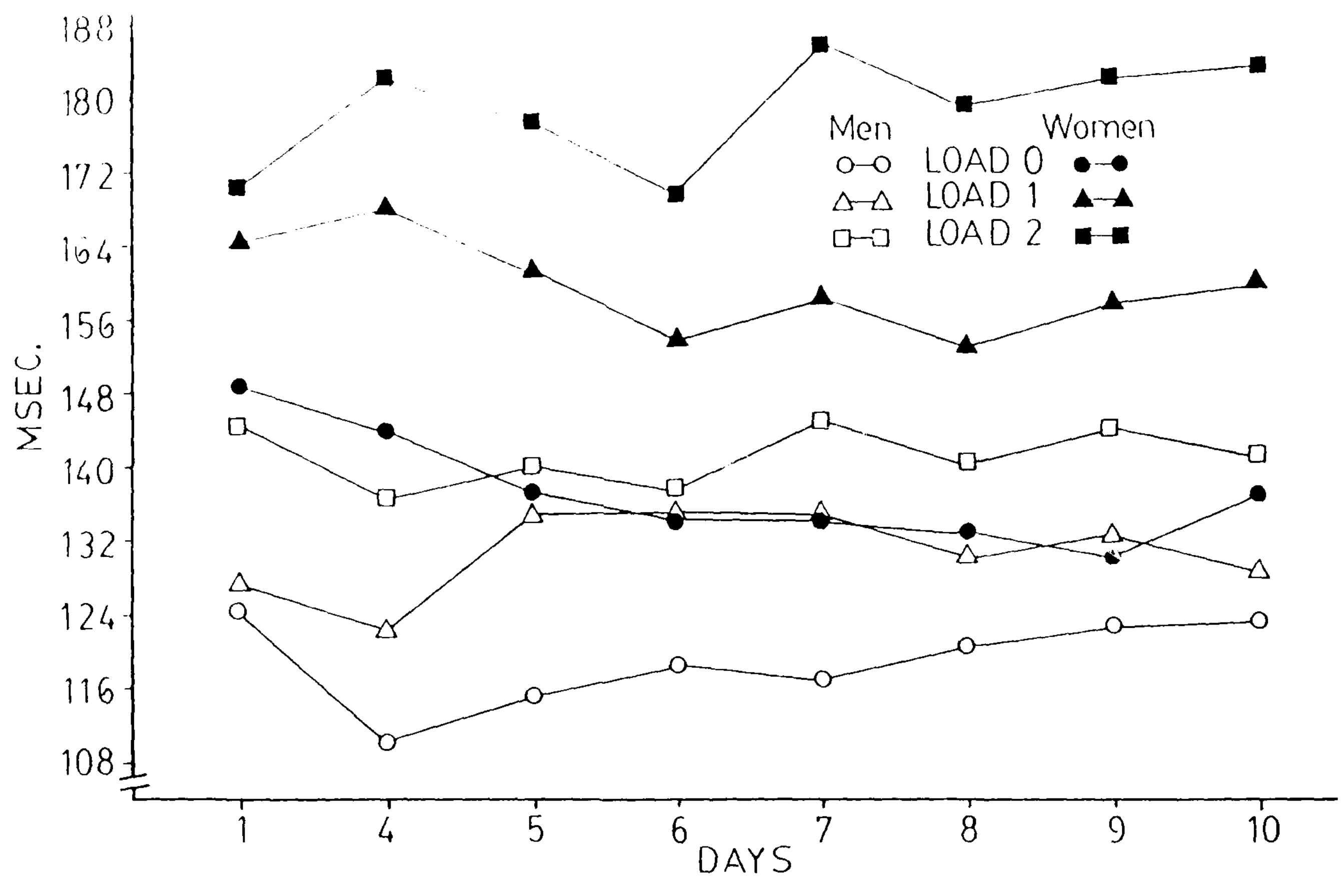


Fig. . Means for First Biceps Burst Duration across Days 1-15, under all Load Conditions, N = 24.

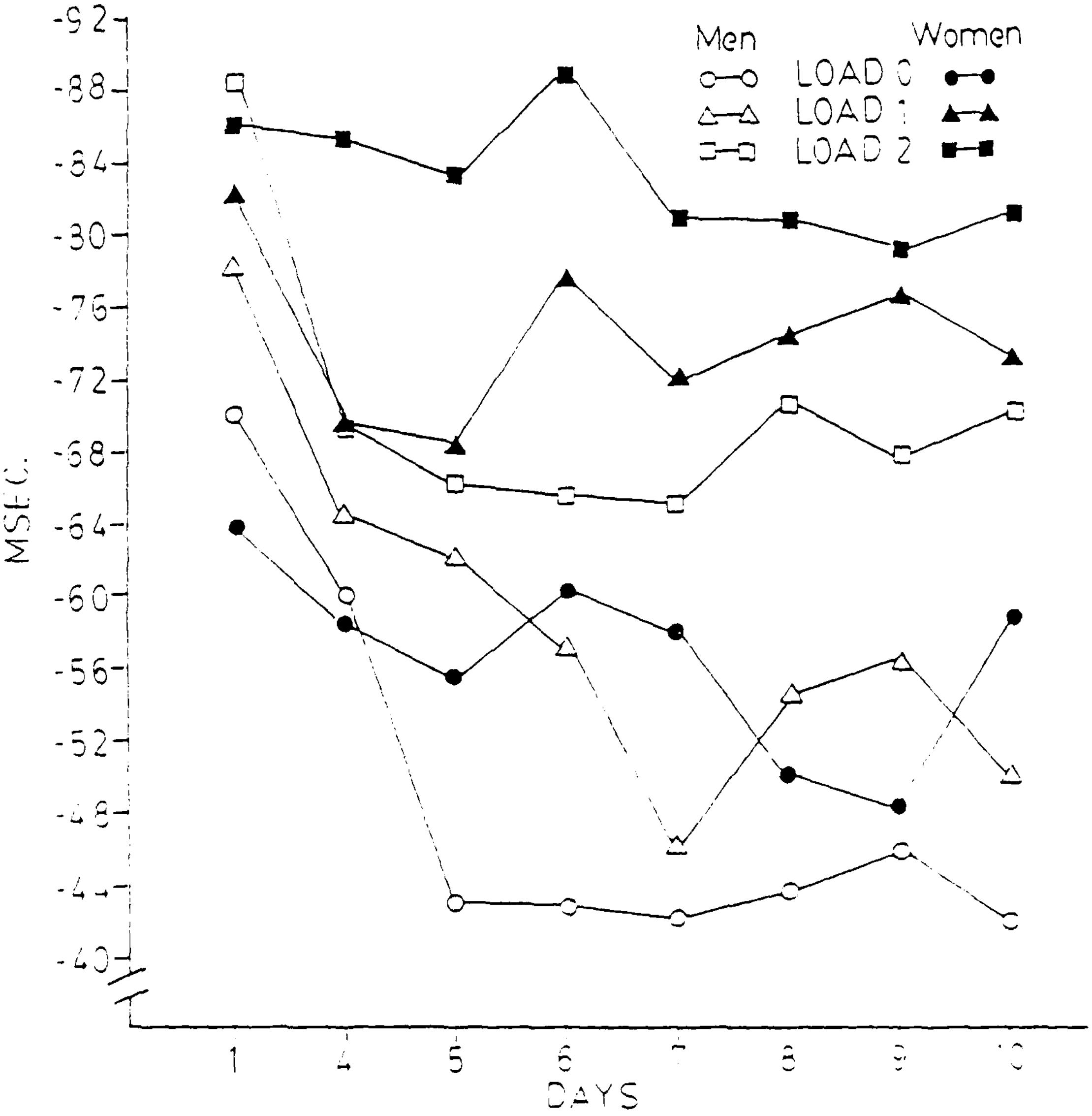


Fig. 10. Means for First Triceps Motor Time across Days 1-15, under all Load Conditions, N = 24.

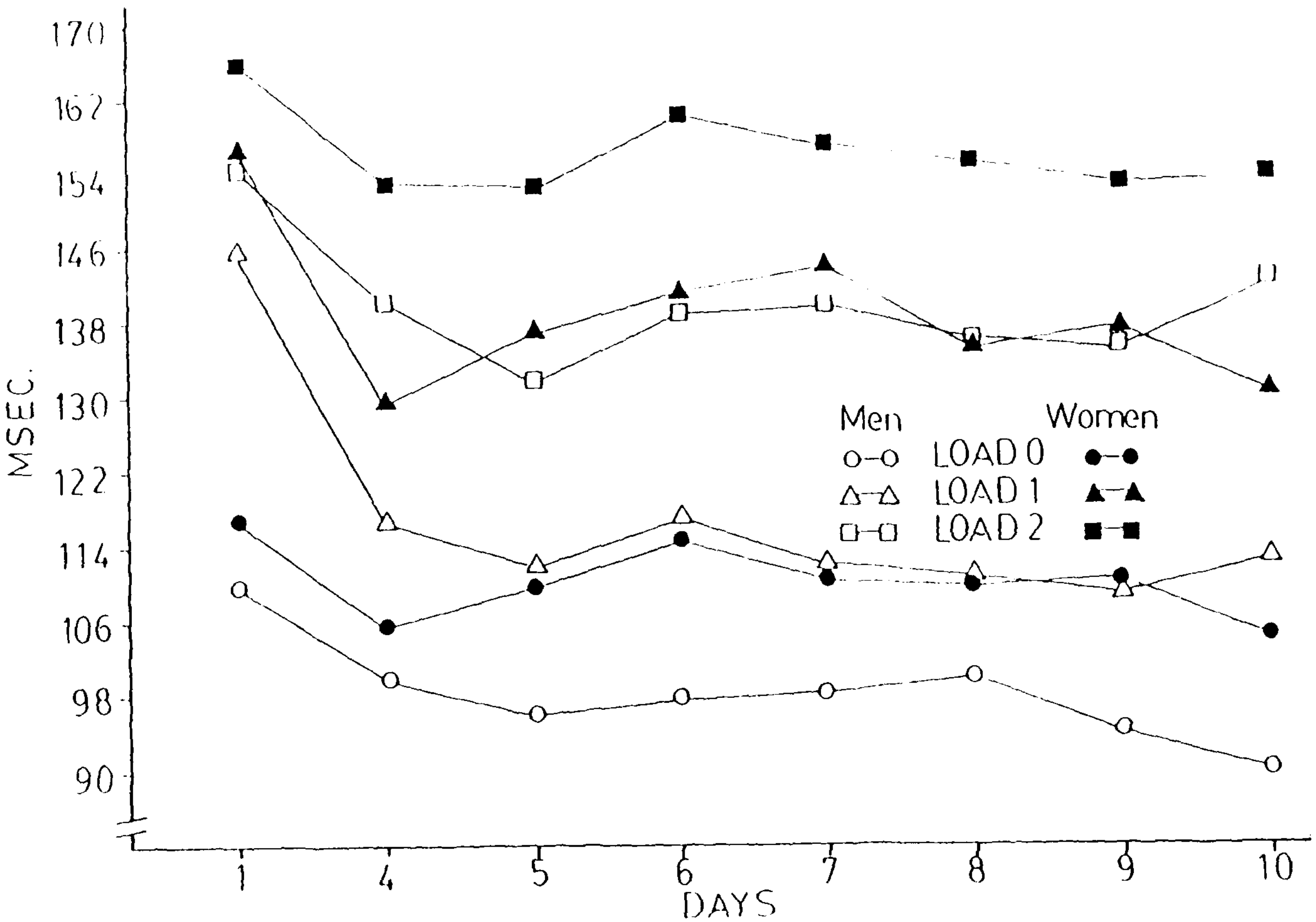


Fig. . Means for Second Triceps Motor Time across Days 1-15, under all Load Conditions, N = 24.

time fluctuation, over days 5 through 10, was greater for the women.

<u>Second triceps duration</u>

The daily means for second triceps burst duration are presented in Tables 6, 7, and 8. Figure 12 revealed a pattern similar to the duration of the first biceps burst (Figure 9). Load conditions 1 and 2 for the women and Load condition 2 for the men exhibited the strongest influence of inertial loading.

<u>Time to the second burst from the biceps and triceps brachii</u>

Figure 13 graphically represents the daily means for the time to the second burst from the biceps brachii presented in Table 9. The onset of the second biceps burst was sharply delayed from day 1 to day 2, thereafter, changes were less dramatic and stabilization occurred by day 5. In contrast to results presented by Wolcott (103) which indicated time to second biceps burst was unaffected by inertial load conditions, Load 2 differed markedly from Load 0 and Load 1, for both women and men. Load 3 was five (5) times the natural moment of inertia in the Wolcott (103) investigation. The increase to seven (7) times the natural moment of inertia, required an adjustment in the time to the second biceps burst.

The daily means for the time to the second triceps burst are presented in Table 9. Figure 14 revealed no discernible difference between Loads 0 and 1 for the men and

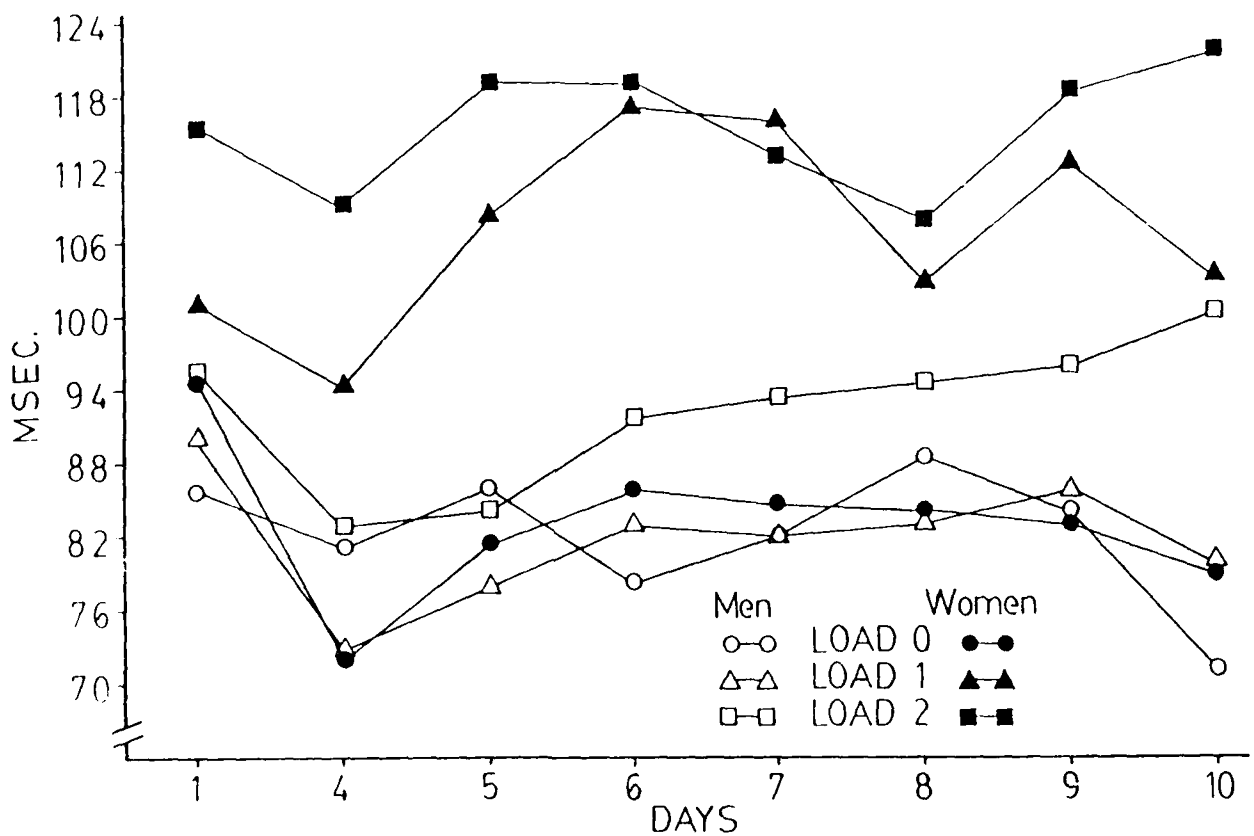


Fig. . Means for Second Triceps Burst Duration across Days 1-15, under all Load Conditions, N = 24.

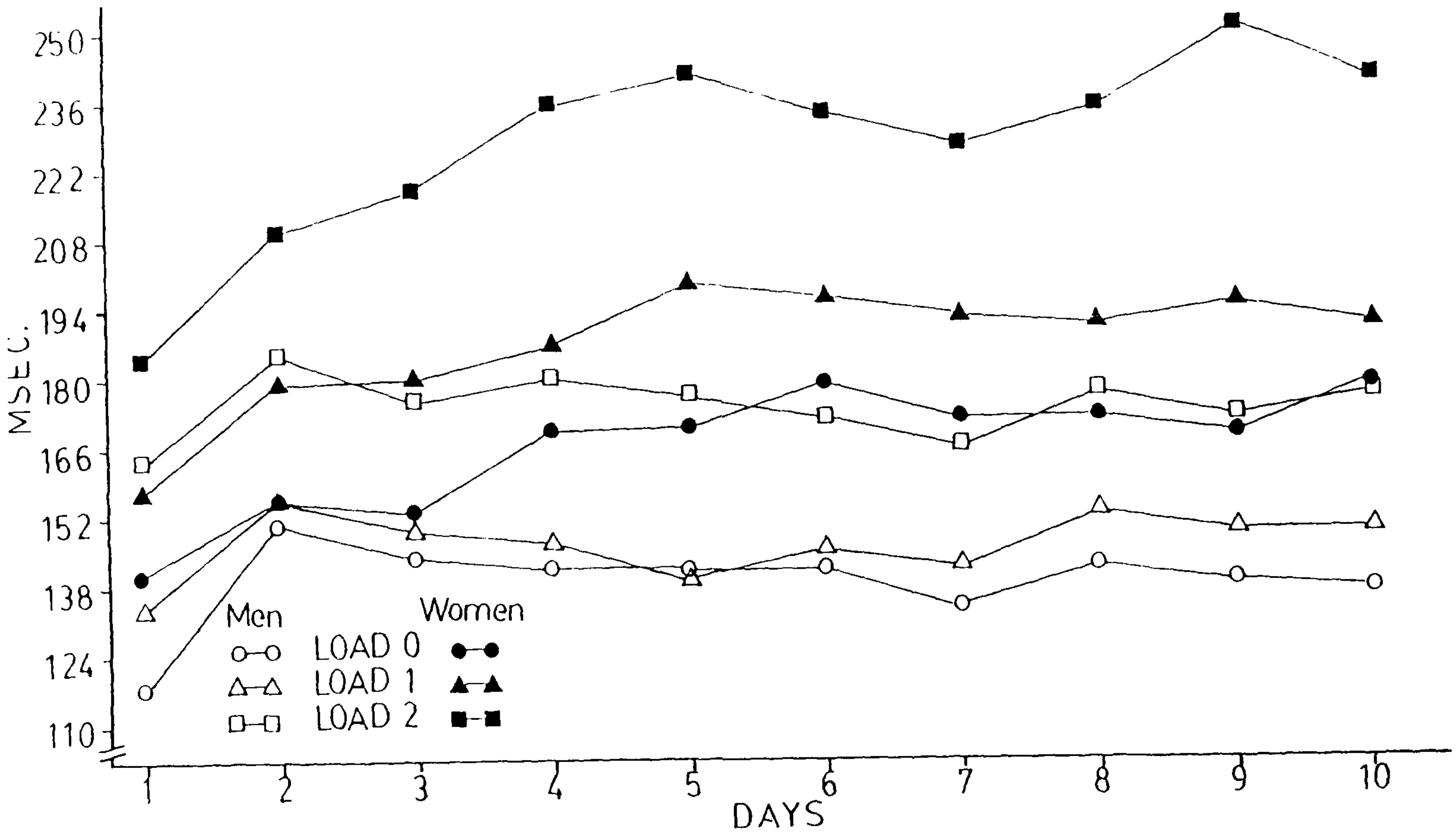


Fig. . Means for the Time to Second Biceps Burst across Days 1-15 for the first ninety degrees of flexion, under all Load Conditions, N 24.

a small, 10 msec. or less, difference for the women. Once again, a markedly different adjustment occurred, for both men and women, under Load 2.

First biceps burst to first triceps burst latency

Figure 15 graphically represents the daily means presented in Tables 6, 7, and 8. The latency increased, for both men and women, under load condition 0 through day 5. Thereafter, the fluctuations occurred in both directions. Load condition 1 increased linearly through day 5, thereafter, the groups went in diametrically opposite directions. Although a pattern of stabilization did not materialize, this criterion measure may be considered to be gender specific, that is, gender differences outweighed inertial load effects.

First biceps burst to second triceps burst latency

Daily means are presented in Tables 6, 7, and 8. Figure 16 illustrates an overall trend towards an increase in this latency. This criterion measure was sensitive to both gender and load condition. Women had longer latencies under all load conditions and the magnitude of the difference increased as inertial loading increased. Within each group, less adjustment was seen between Loads 0 and 1 than between Loads 1 and 2.

Biceps silent period

Figure 17 graphically illustrates the daily means presented in Tables 6, 7, and 8. Dramatic increases in the

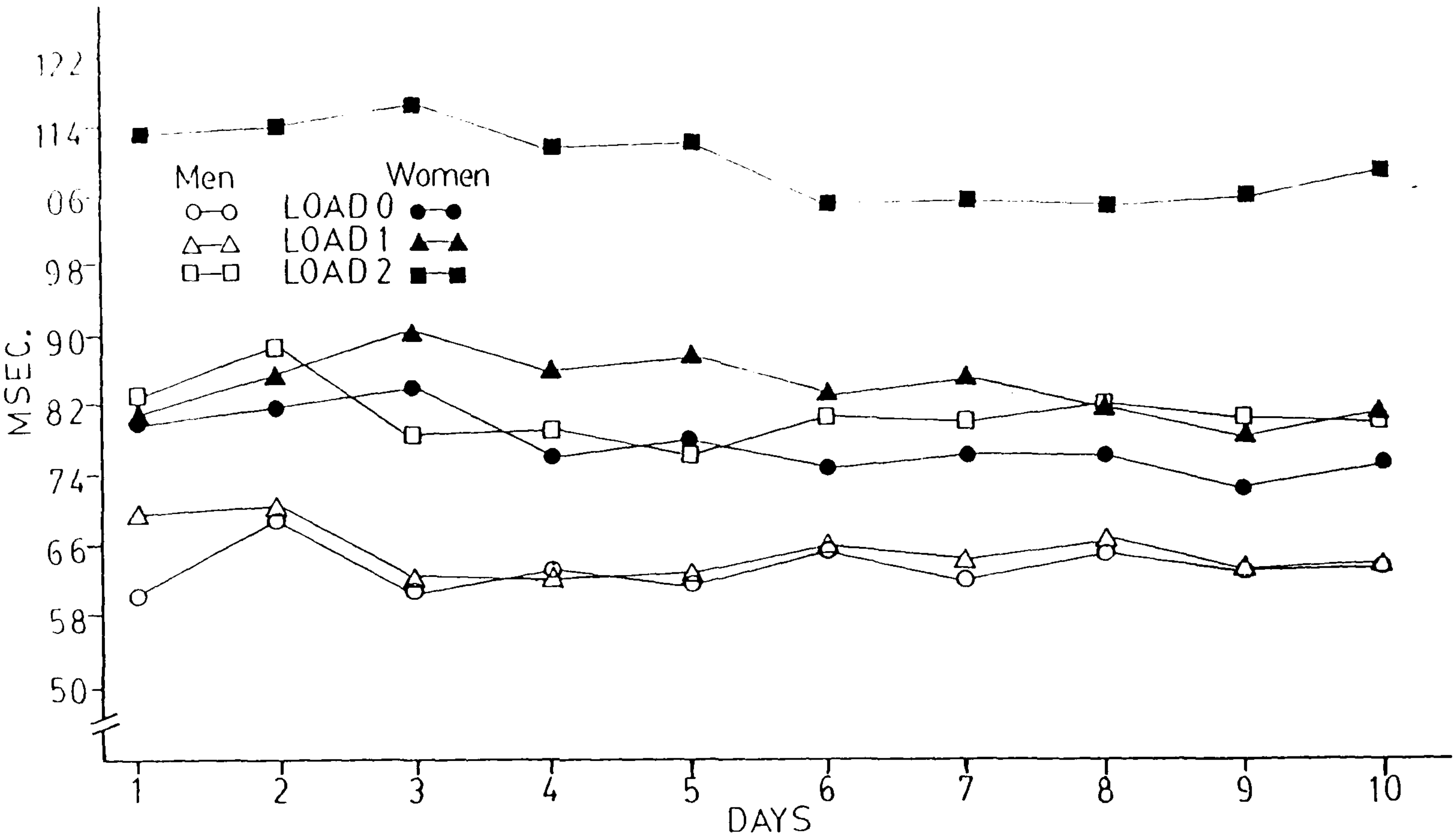


Fig. . Means for the Time to Second Triceps Burst across Days 1-15 for the first ninety degrees of flexion, under all Load Conditions, N =24.

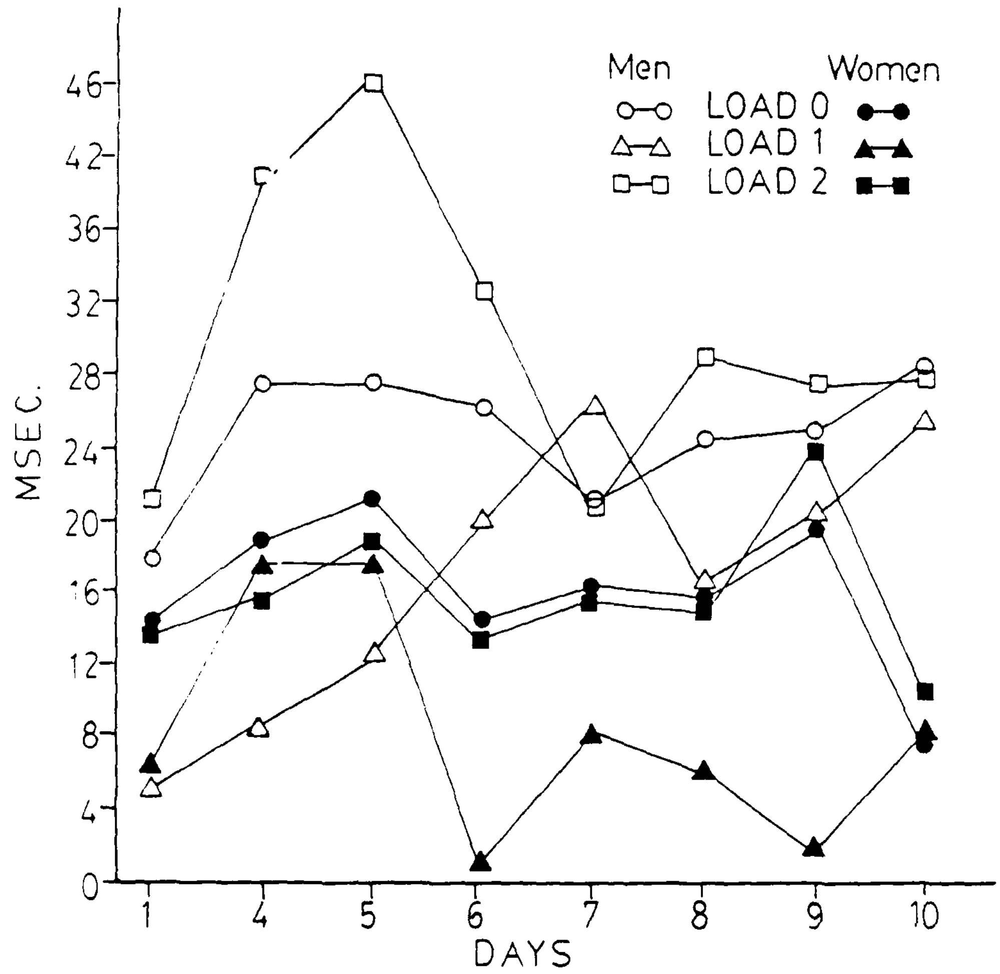


Fig. . Means for First Biceps Burst to First Triceps Burst Latency across Days 1-15, under all Load Conditions, N = 24.

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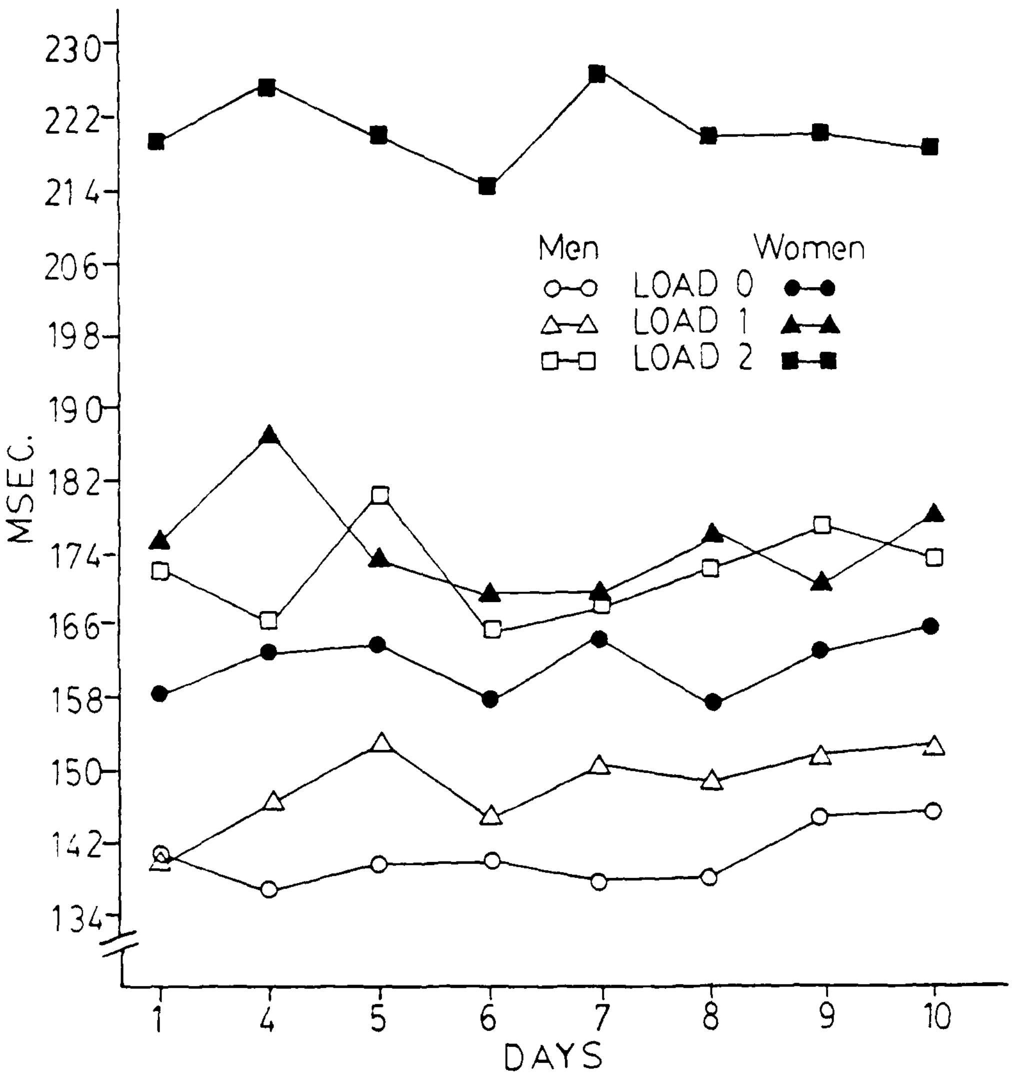

Fig. . Means for First Biceps Burst to Second Triceps Burst Latency across Days 1-15, under all Load Conditions, N = 24.

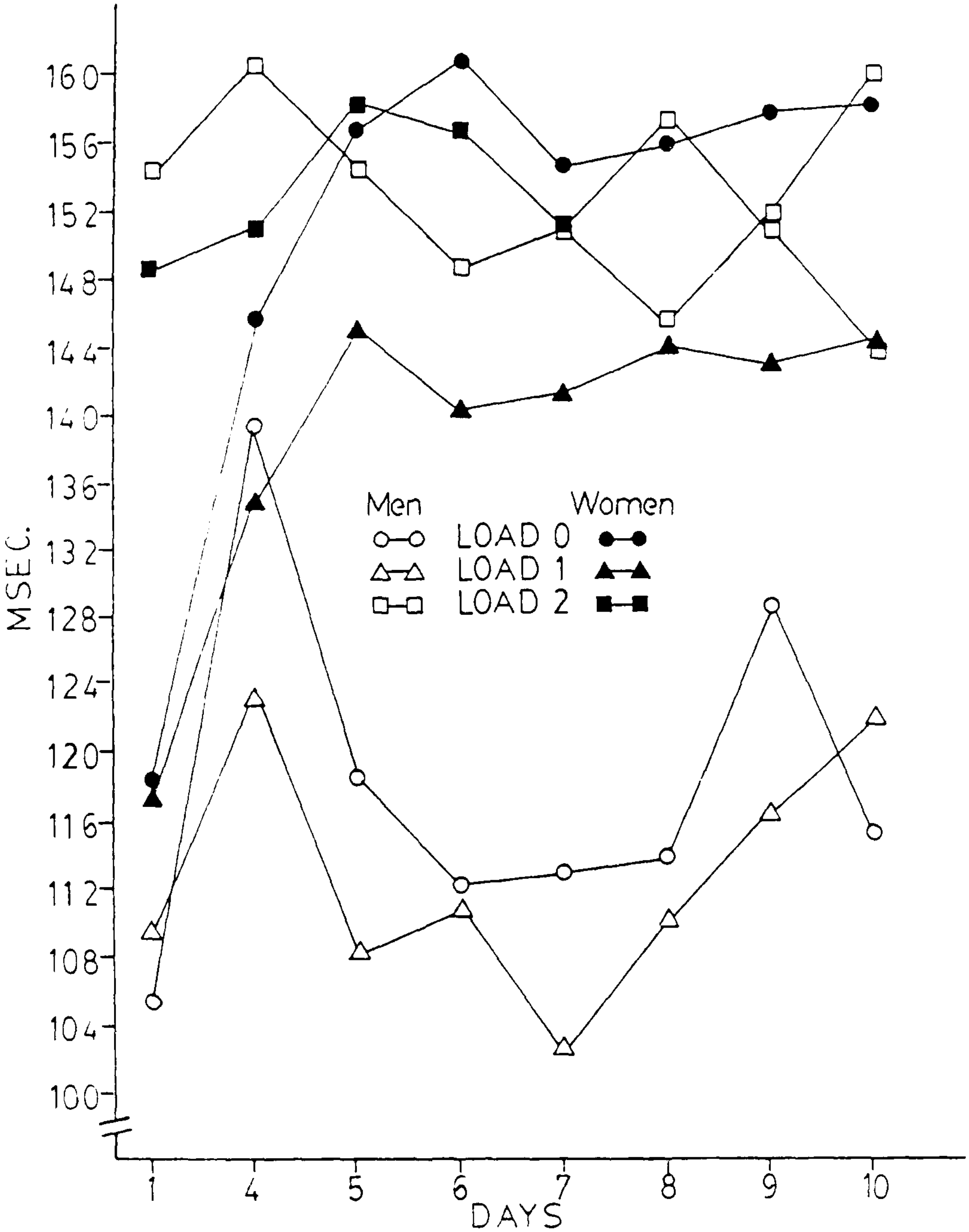

Fig. . Means for Biceps Silent Period across Days 1-15, under all Load Conditions, N = 24.

length of the biceps silent period were evident under Load Conditions 0 and 1, for both men and women. Less dramatic increases occurred under Load Condition 2. A pronounced biceps silent period coupled with the occurrence of the second triceps burst are characteristic of practiced forearm speed movements. Since movement time decrements also occurred, the changes in biceps silent period must be viewed relatively. Except for the formidable influence of Load 2, the reponse of this criterion measure appears to be gender specific.

Second triceps burst to maximal acceleration latency

Figure 18 is a graphic representation of the daily means presented in Tables 6, 7, and 8. Negative values indicate maximal acceleration preceded the second triceps burst. The women started with longer latencies, for all load conditions, and consequently were able to effect greater decreases particularly under Loads 1 and 2. Changes effected by the men were more modest.

Second triceps burst to zero acceleration latency

Daily means are presented in Tables 6, 7, and 8. Figure 19 graphically illustrates the women and men were most successful in decreasing this latency under load condition 1. This criterion measure is indicative of how quickly the second triceps burst effects limb deceleration. Both extremes in inertial loading (Loads 0 and 2) produced negligible changes.

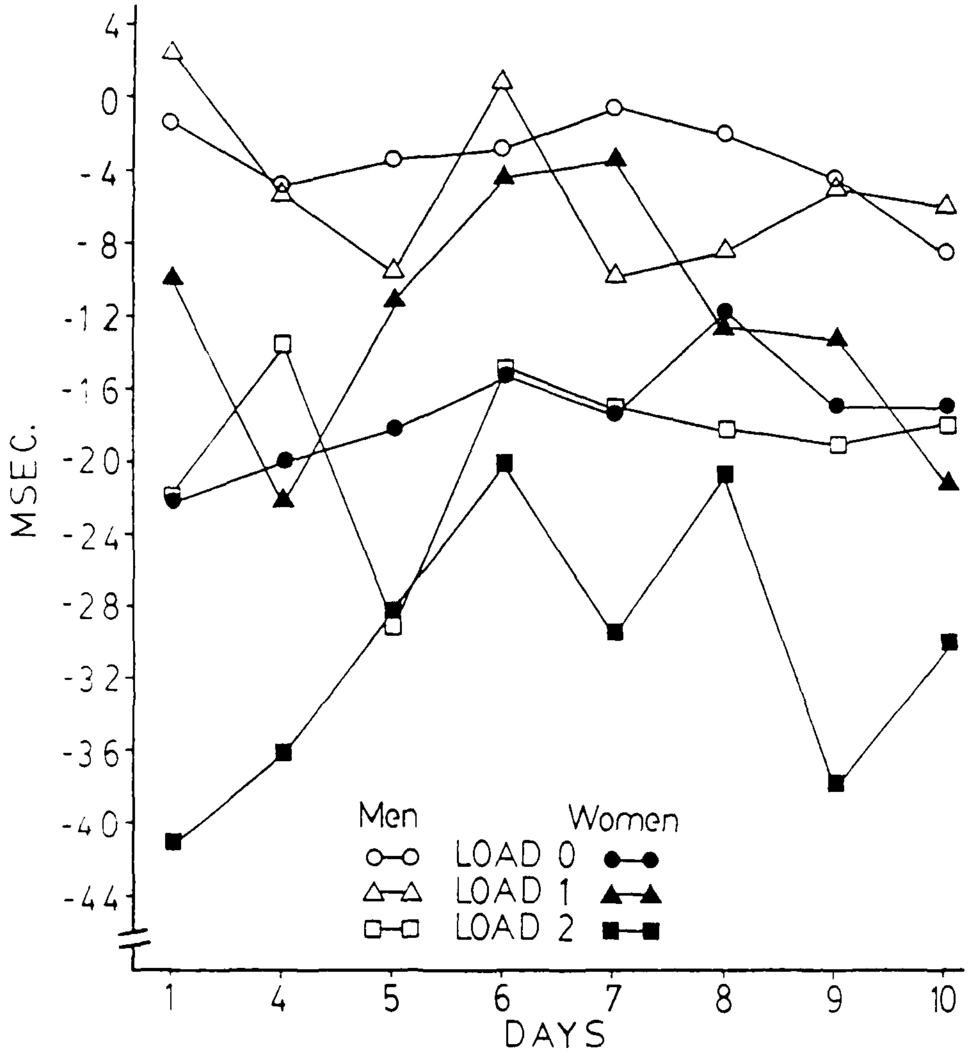

Fig. . Means for Second Triceps Burst to Maximal Acceleration Latency across Days 1-15, under all Load Conditions, N = 24.

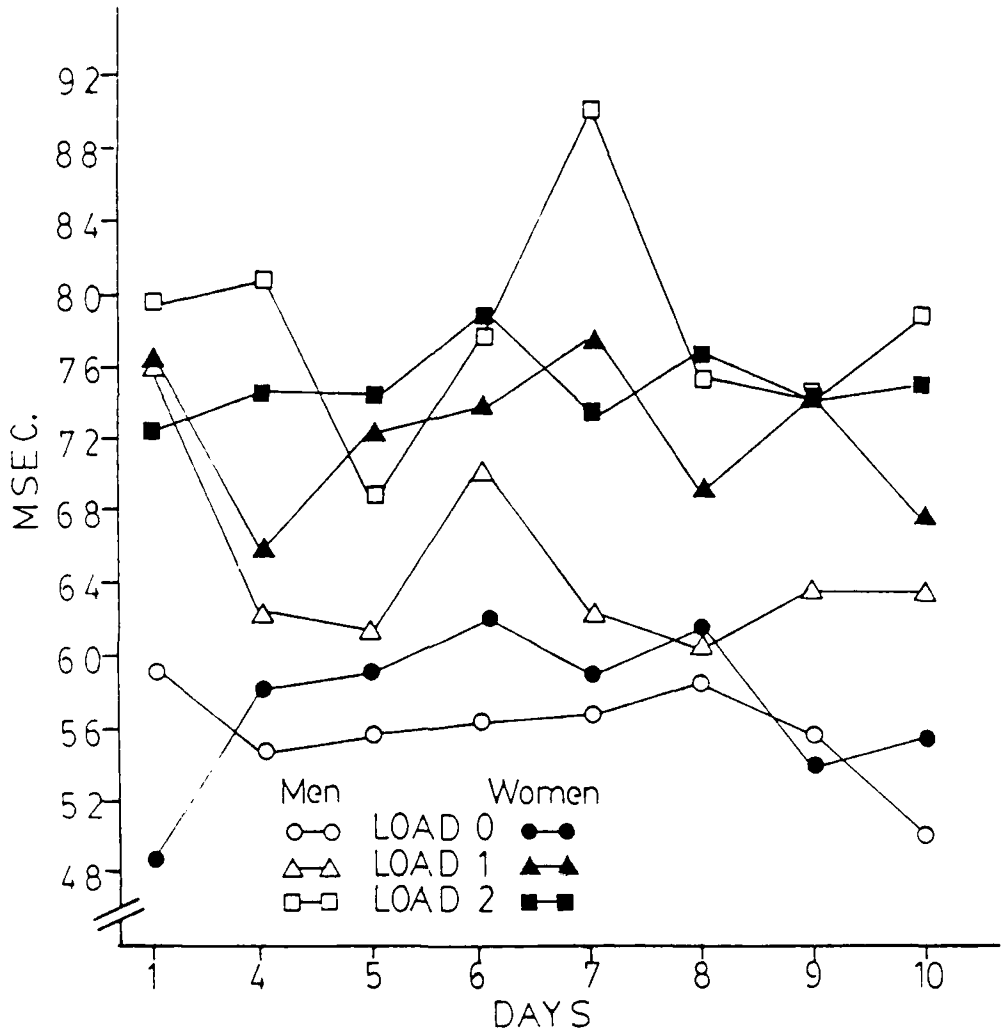

Fig. . Means for Second Triceps Burst to Zero Acceleration Latency across Days 1-15, under all Load Conditions, N = 24.

Slope of the first biceps burst EMG

Figure 20 dramatically illustrates the gender specific characteristic of this criterion measure. Daily means are presented in Tables 6, 7, and 8. Though clearly more biceps activity, as reflected by an increased slope, was required as inertial loads increased the male slopes varied minutely. Though the women were able to narrow the range of biceps activity among load conditions, they were less able to narrow the difference between genders. Changes in frequency would not be discernible.

Slope of the second triceps burst EMG

Daily means for this criterion measure are presented in Tables 6, 7, and 8. Figure 21 illustrates the marked decreases in this criterion measure achieved by the women under load conditions 1 and 2. Though load differences remained, the men were able to narrow range of second triceps slopes. As would be expected the amount of second triceps burst activity was influenced by the magnitude of the inertial load.

Ratio between total biceps EMG and total triceps EMG

Daily means for this criterion measure are presented in Tables 6, 7, and 8. Figure 22 reveals the dramatic decreases in this ratio, under load conditions 1 and 2, for both women and men. The women exhibited greater fluctuation over the six experimental days, particularly load conditions 1 and 2. At the lowest level, men load 0, the ratio was

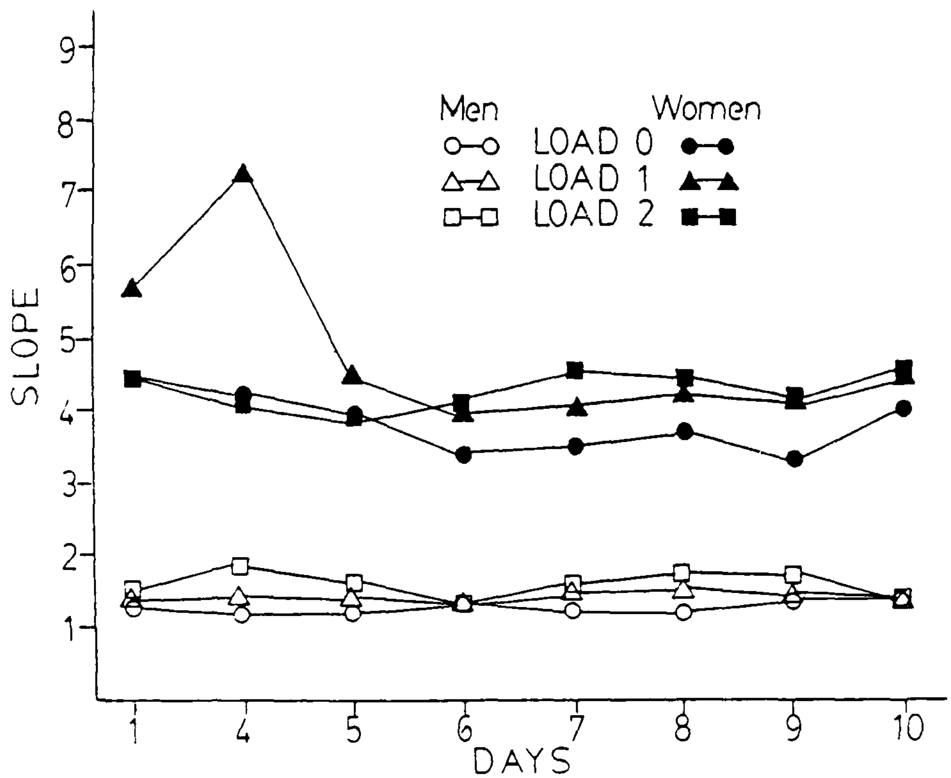

Fig. . Means for the Slope of the First Biceps Burst EMG across Days 1-15, under all Load Conditions, N = 24.

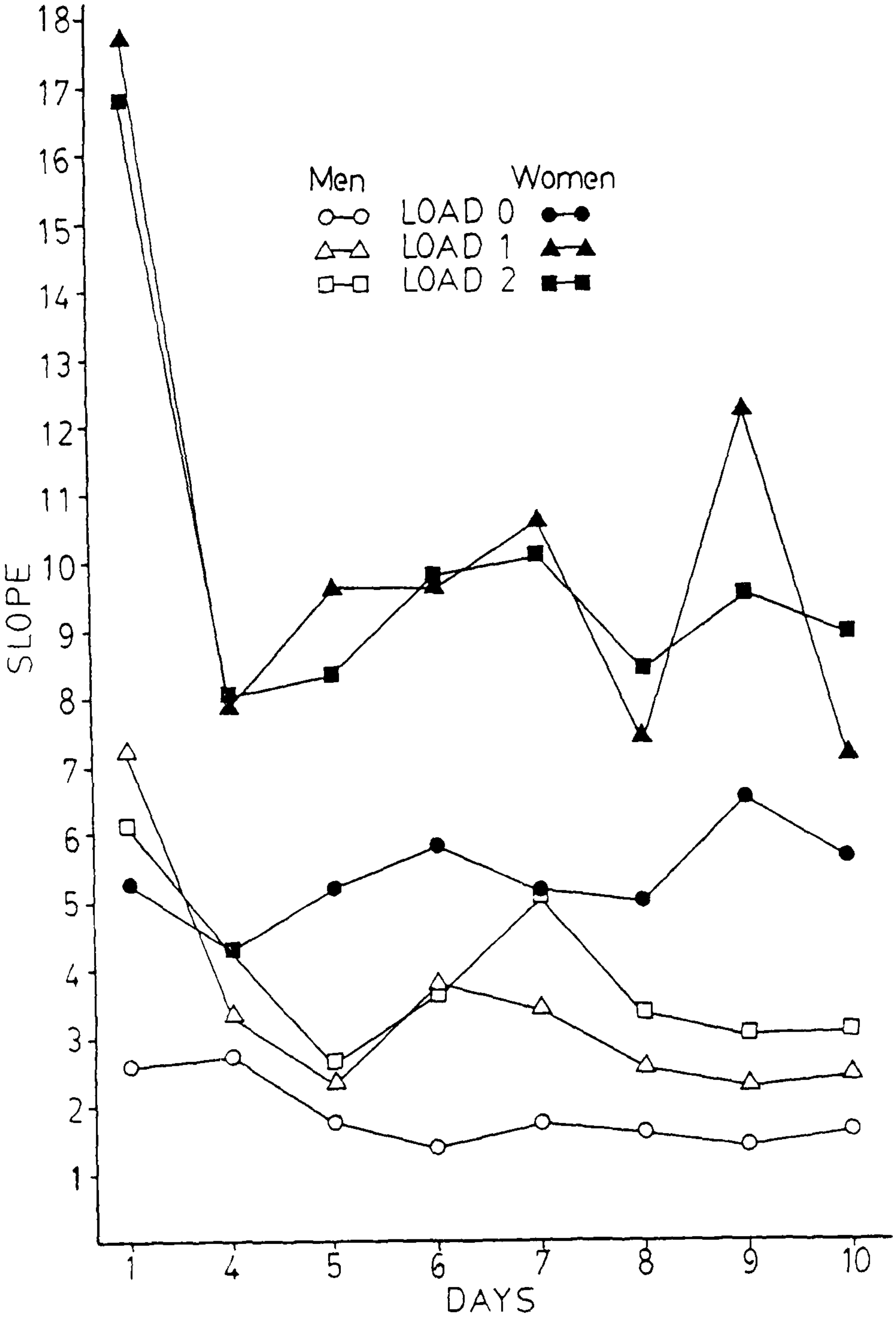

Fig. . Means for the Slope of the Second Triceps Burst EMG across Days 1-15, under all Load Conditions, N = 24.

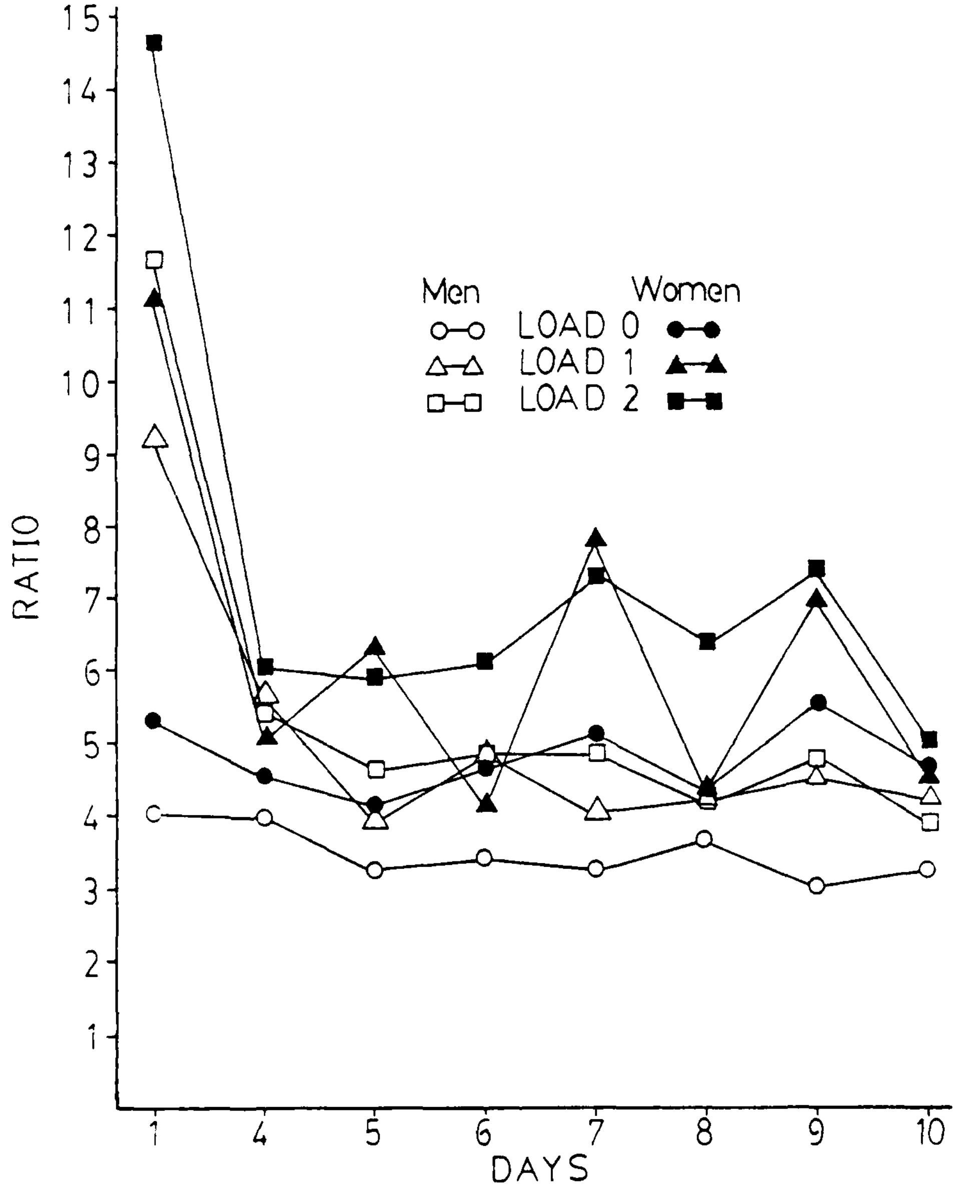

Fig. . Means for the Ratio between Total Biceps EMG and Total Triceps EMG across Days 1-15, under all Load Conditions, N = 24.

approximately 3.3:1 between total biceps and total triceps electromyographic activity.

Maximal displacement and accuracy

As illustrated in Figure 23, the men were more accurate under all load conditions. The daily means for maximal displacement are presented in Tables 6, 7, and 8. Accuracy denoted that segment from 90 degrees to the actual displacement. All daily means for accuracy was positive which indicated a consistent overshoot of the 90 degree target. Within both groups, it became increasingly more difficult to stop at ninety degrees as the inertial load increased.

Practice effects on selected criterion measures

The criterion measures recorded during movement to maximal displacement were collected on day 1 and day 4. The data collected was submitted to variance analysis, however, changes which occurred over days 2 and 3 will remain obscured. The means for days 1 and 4 for all criterion measures to maximal displacement are presented in Tables 6, 7, and 8. A summary of the results of the repeated measures variance analysis is presented in Table 10. The complete repeated measures ANOVA tables are presented in Appendix E.

Significant differences existed between groups for movement time, acceleration time, and first biceps burst duration. The analysis yielded significant Days effect for movement time, second triceps duration, maximal displacement, and accuracy. The inertial loading analysis yielded

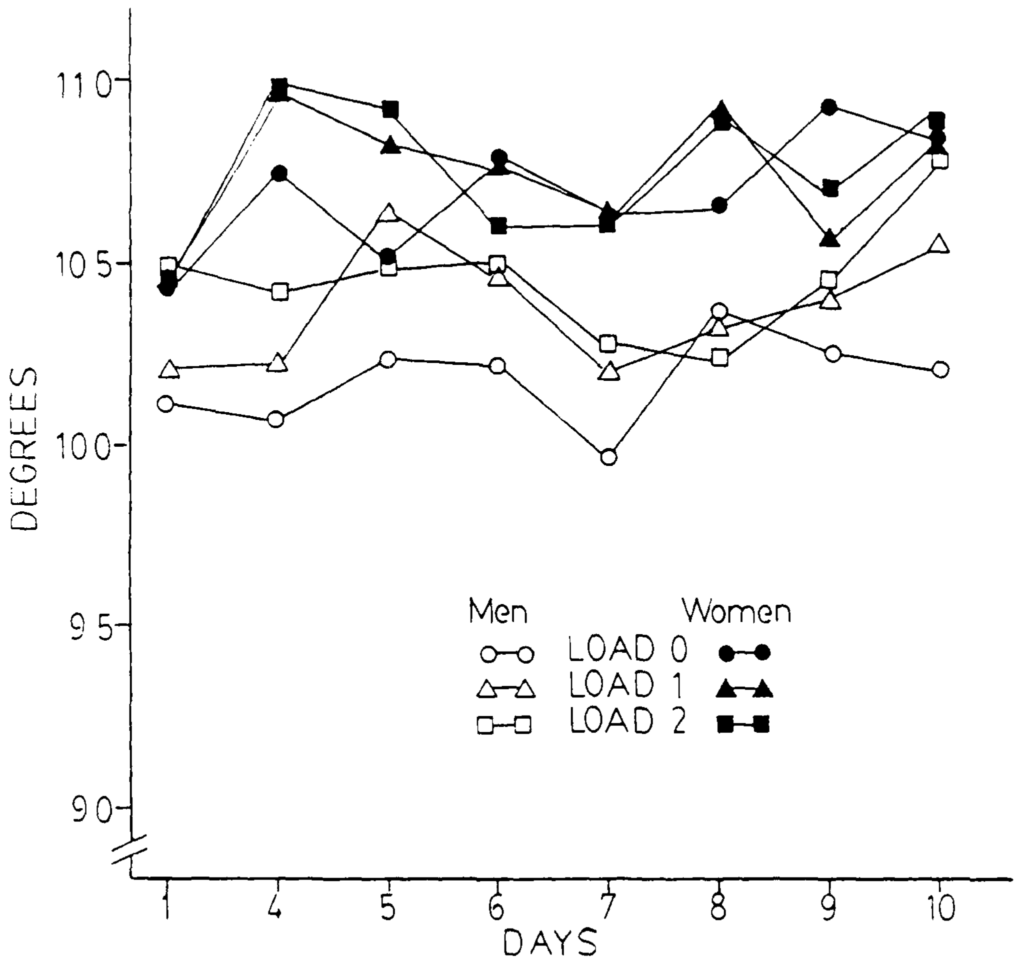

Fig. . Means for Maximal Displacement across Days 1-15, under all Load Conditions, N = 24.

TABLE 10

SUMMARY OF F RATIOS FOR GROUPS, DAYS, AND LOADS EFFECTS INCLUDING LINEAR AND QUADRATIC COMPONENTS FOR THE CRITERION MEASURES TO MAXIMAL DISPLACEMENT OVER PRACTICE DAYS 1 AND 4, N = 24.***

MEASURES	GROUPS	DAYS	LOADS
MOVEMENT TIME	36.71*	24.03*	139.40**
Linear			272.28**
Quadratic			6.51
ACCELERATION TIME	24.24*	.03	39.36**
Linear			75.00**
Quadratic			3.71
TIME TO MAXIMAL ACCELERATION	10.00	.19	.10
Linear			.06
Quadratic			.13
BICEPS(1B) MOTOR TIME	4.15	2.15	34.87**
Linear			69.61**
Quadratic			.14
BICEPS(1B) DURATION	53.40*	.92	15.61*
Linear			31.22**
Quadratic			.00
BICEPS SILENT PERIOD	.06	7.04	5.04
Linear			5.81
Quadratic			4.26
TRICEPS(1B) MOTOR TIME	.40	4.46	1.53
Linear			2.59
Quadratic			.48
TRICEPS(2B) MOTOR TIME	1.02	11.45	24.55**
Linear			48.27**
Quadratic			.83
TRICEPS(2B) DURATION	2.97	50.84*	12.42*
Linear			24.08*
Quadratic			.75

TABLE 10 (con't.)

MEASURES	GROUPS	DAYS	LOADS
BICEPS(1B) TO TRICEPS(1B) LATENCY	.23	4.00	1.48
Linear			.18
Quadratic			2.78
BICEPS(1B) TO TRICEPS(2B) LATENCY	7.78	.71	13.75*
Linear			25.65**
Quadratic			1.85
TRICEPS(2B) TO MAXIMAL ACCELERATION LATENCY	4.77	.01	5.99
Linear			6.31
Quadratic			5.67
TRICEPS(2B) TO ZERO ACCELERATION LATENCY	.15	.55	10.14
Linear			19.27*
Quadratic			1.01
MAXIMAL DISPLACEMENT	4.52	23.32*	7.35*
Linear			14.69*
Quadratic			.01
SLOPE FOR BICEP(1B) EMG	10.51	.71	.82
Linear			.04
Quadratic			1.60
SLOPE FOR TRICEPS(2B) EMG	8.68	8.12	4.99
Linear			7.15
Quadratic			2.82
BICEPS(1B)/TRICEPS(2B)	.78	.79	16.45**
Linear			32.85**
Quadratic			.05
TOTAL BICEPS EMG/TOTAL TRICEPS EMG	.13	7.67	2.02
Linear			3.89
Quadratic			.15
ACCURACY	4.62	20.95*	6.05
Linear			12.08*
Quadratic			.02

* $p < .01$
** $p < .05$
***Complete Repeated Measures ANOVA tables are presented in Appendix E.

significant overall and linear trends for all the criterion measures except for time to maximal acceleration, biceps silent period, first triceps motor time, first biceps burst to first triceps burst latency, second triceps burst to maximal acceleration latency, slope for first biceps burst EMG, slope for second triceps burst EMG, and the ratio between total biceps EMG and total triceps EMG.

The criterion measures collected during the first ninety degrees of flexion were recorded on each of the four stabilization days. The means for each criterion measure, for men and women, under all load conditions are presented in Table 11. The criterion measures collected during the first ninety degrees of forearm flexion were submitted to repeated measures analysis of variance. A summary of the results of the variance analysis is presented in Table 12. The complete Repeated Measures ANOVA tables are presented in Appendix E.

Significant differences existed between groups for movement time, acceleration time, and the time to the second triceps burst. The analysis yielded significant overall and linear trends for the Days effect in movement time and the time to the second triceps burst. The inertial loading analyis yielded significant overall, linear, and quadratic trends for all the criterion measures. Trials effect analysis yielded significant overall and linear trends for movement time and the time to the second biceps burst. The

TABLE 11

MEAN VALUES OF 15 TRIALS FOR THE CRITERION MEASURES DURING THE FIRST NINETY DEGREES OF FOREARM FLEXION UNDER ALL LOAD CONDITIONS, N = 24.*

MEASURES	DAY 1		DAY 2		DAY 3		DAY 4	
LOAD 0	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
MOVEMENT TIME (90°)	162.2	135.5	151.7	133.1	147.6	135.4	143.0	131.5
ACCELERATION TIME	132.9	120.2	135.2	123.7	136.8	127.0	131.6	125.6
BICEPS SECOND BURST	139.0	118.0	154.9	150.3	152.7	144.0	169.7	141.2
TRICEPS SECOND BURST	80.0	59.4	81.9	69.4	84.2	60.9	76.0	62.6
LOAD 1								
MOVEMENT TIME (90°)	178.2	151.0	169.9	144.9	165.0	148.8	163.6	141.6
ACCELERATION TIME	142.0	136.9	143.3	133.9	145.7	134.2	140.3	131.9
BICEPS SECOND BURST	157.0	132.8	178.3	155.5	179.8	149.5	186.7	146.7
TRICEPS SECOND BURST	82.5	69.8	85.3	70.7	91.0	62.3	86.5	61.8
LOAD 2								
MOVEMENT TIME (90°)	215.1	171.0	206.2	169.7	202.1	170.8	202.8	170.6
ACCELERATION TIME	155.3	148.9	162.2	152.5	165.7	151.4	162.4	149.9
BICEPS SECOND BURST	183.8	163.6	209.3	184.6	217.0	175.5	234.2	179.6
TRICEPS SECOND BURST	113.2	83.5	114.0	88.4	115.9	77.8	111.3	79.6

*All measures are expressed in milliseconds.

TABLE 12

SUMMARY OF F RATIOS FOR GROUPS, DAYS, LOADS, AND TRIALS EFFECTS INCLUDING LINEAR, QUADRATIC, AND CUBIC COMPONENTS FOR THE CRITERION MEASURES FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION CVER FOUR PRACTICE DAYS, N = 24.***

MEASURES	GROUPS	DAYS	LOADS	TRIALS
MOVEMENT TIME (90°)	14.49**	6.68**	406.90**	9.43**
Linear		18.05**	780.32**	17.29**
Quadratic		1.61	33.47**	1.57
Cubic		.37		
ACCELERATION TIME	4.94*	1.98	164.33**	1.87
Linear		.59	318.99**	1.33
Quadratic		4.84*	9.67**	2.42
Cubic		.51		
TIME TO 2ND BICEPS BURST	3.33	6.37**	72.55*	11.37**
Linear		13.61**	138.29**	21.85**
Quadratic		2.94	6.80*	.89
Cubic		2.55		
TIME TO 2ND TRICEPS BURST	14.21**	.99	86.59**	1.92
Linear		.79	151.03**	3.08
Quadratic		1.71	22.15**	.76
Cubic		.48		

* $p < .05$
** $p < .01$
***Complete Repeated Measures ANOVA tables are presented in Appendix E.

time to the second biceps burst was not significantly different for women and men. The time to the second triceps burst was not significant in the Days effect analysis. Acceleration time and the time to the second triceps burst were not significant in the Trials effect analysis. As an indication of the relative stability or instability present in the criterion measures, a reliability analysis of variance was conducted. Variance estimates and intraclass reliability coefficients are presented in Table 13.

Baseline stability and reliability

Means, standard deviations, standard errors, maximums, minimums, and ranges for the criterion measures recorded during the first ninety degrees of forearm flexion and for the criterion measures recorded during forearm flexion to maximal displacement, are presented in Tables 14, 15, 16, and 17. Lagasse (54) reported a mean value of 153 msec. for movement time to ninety degrees, under the natural moment of inertia. Wolcot (103) reported mean values of 142 msec., 157 msec., and 181 msec. for Load 1 (no load), Load 2 (two times the natural moment of inertia), and Load 3 (five times the natural moment of inertia), respectively. Though Wolcott (103) investigated class A (stopped by impact) movement, the values were reported for the first ninety degrees of forearm flexion. Comparisons of movement time, under Load 0, for the first ninety degrees of forearm flexion (Table 17) reveal the women in the present investigation

TABLE 13

VARIANCE ESTIMATES AND INTRACLASS RELIABILITY COEFFICIENTS FOR THE CRITERION MEASURES FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER FOUR PRACTICE DAYS, N = 24.*

MEASURES	σ^2 DAYS		σ^2 TRIALS		TRUE SCORE		R	
LOAD 0	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
MOVEMENT TIME (90°)	138.13	77.51	24.47	95.64	202.65	238.41	.85	.90
ACCELERATION TIME	34.41	63.30	27.61	26.84	81.57	193.76	.88	.91
TIME TO 2ND BICEPS BURST	537.76	482.79	353.78	103.99	670.55	697.05	.80	.84
TIME TO 2ND TRICEPS BURST	190.21	92.72	70.31	48.11	229.14	104.47	.81	.79
LOAD 1								
MOVEMENT TIME (90°)	89.11	70.15	161.05	86.83	221.13	254.71	.86	.91
ACCELERATION TIME	25.71	36.77	58.59	67.95	59.42	209.08	.84	.93
TIME TO 2ND BICEPS BURST	737.72	424.90	398.21	113.15	804.92	917.99	.79	.89
TIME TO 2ND TRICEPS BURST	129.43	89.76	185.51	73.27	209.21	147.28	.81	.84
LOAD 2								
MOVEMENT TIME (90°)	-81.73	-27.46	570.09	286.71	321.84	235.20	.87	.91
ACCELERATION TIME	5.03	-13.40	151.34	194.23	76.66	126.51	.85	.89
TIME TO 2ND BICEPS BURST	1088.89	219.21	651.72	664.41	1420.08	1372.96	.81	.93
TIME TO 2ND TRICEPS BURST	27.65	88.22	426.30	183.56	300.22	175.85	.88	.82

*Negative variance estimates were set to zero in the computation of intraclass reliability coefficients.

TABLE 14

MEANS, STANDARD DEVIATIONS, STANDARD ERRORS, MAXIMUMS, MINIMUMS, AND RANGES FOR THE CRITERION MEASURES OVER DAYS 5 - 10 UNDER LOAD CONDITION 0, N = 24.*

	MEAN $\bar{X}$		STANDARD DEVIATION		STANDARD ERROR		MAXIMUM		MINIMUM		RANGE	
	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
MOVEMENT TIME	203.4	179.2	3.08	1.46	1.26	.60	207.2	181.0	200.0	176.8	7.2	4.2
ACCELERATION TIME	152.2	138.8	1.75	2.12	.72	.87	154.4	142.6	149.3	136.7	5.1	5.9
TIME TO MAXIMAL ACCELERATION	77.4	79.6	3.16	1.69	1.29	.69	80.3	82.6	72.1	78.0	8.2	4.6
BICEPS MOTOR TIME (1st Burst)	71.6	61.4	2.16	1.24	.88	.51	73.9	63.2	68.5	60.2	5.4	3.0
BICEPS DURATION (1st Burst)	134.0	119.2	2.72	3.21	1.11	1.31	137.2	122.7	129.8	114.7	7.4	8.0
BICEPS SILENT PERIOD	157.1	116.7	2.62	5.96	1.07	2.43	161.0	127.9	154.1	112.1	6.9	15.8
TRICEPS MOTOR TIME(1st Burst)	55.0	43.1	4.88	1.54	1.99	.63	60.4	46.0	48.1	41.8	12.3	4.2
TRICEPS MOTOR TIME(2nd Burst)	109.7	95.9	3.52	3.47	1.44	1.42	114.7	99.8	103.7	90.1	11.0	9.7
TRICEPS DURATION (2nd Burst)	83.0	81.6	2.41	6.15	.98	2.51	85.6	88.3	79.0	71.2	6.6	17.1
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	15.6	25.4	4.66	2.56	1.90	1.04	19.2	28.1	7.6	21.1	11.6	7.0
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	161.4	140.6	3.68	3.57	1.50	1.46	165.3	144.9	165.3	136.4	9.0	8.5
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	-16.3	-3.6	2.31	2.68	.94	1.09	-12.0	-.7	-18.3	-8.5	6.3	7.8
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	58.5	55.5	3.31	2.87	1.35	1.17	62.0	58.3	53.9	50.0	8.1	8.3
MAXIMAL DISPLACEMENT	107.2	102.0	1.46	1.36	.42	.39	109.1	103.6	105.2	99.5	3.9	4.1
SLOPE FOR BICEPS(1B) EMG	3.6	1.3	.28	.08	.08	.02	3.9	1.3	3.2	1.1	.7	.2
SLOPE FOR TRICEPS(2B) EMG	5.5	1.6	.55	.15	.16	.04	6.5	1.7	5.0	1.4	1.5	.3
BICEPS(1B)/TRICEPS(2B) EMG	41.9	41.4	6.10	2.87	1.76	.83	48.7	44.3	32.3	36.8	16.4	7.5
BICEPS EMG/TRICEPS EMG	4.7	3.3	.52	.19	.15	.05	5.5	3.6	4.1	3.0	1.4	.6

*Displacement is expressed in degrees, all other measures are expressed in milliseconds.

TABLE 15

MEANS, STANDARD DEVIATIONS, STANDARD ERRORS, MAXIMUMS, MINIMUMS, AND RANGES FOR THE CRITERION MEASURES OVER DAYS 5 - 10 UNDER LOAD CONDITION ι, N = 24.*

	MEAN $\overline{X}$		STANDARD DEVIATION		STANDARD ERROR		MAXIMUM		MINIMUM		RANGE	
	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
MOVEMENT TIME	230.7	190.6	2.57	2.93	1.05	1.20	234.0	193.4	226.7	186.1	7.3	7.3
ACCELERATION TIME	165.6	141.8	3.11	1.18	1.27	.48	168.8	143.2	161.0	140.4	7.8	2.8
TIME TO MAXIMAL ACCELERATION	82.0	72.2	3.67	1.20	1.50	.49	87.4	73.9	77.8	70.3	9.6	3.6
BICEPS MOTOR TIME (1st Burst)	81.6	74.4	2.85	2.78	1.16	1.13	85.8	77.4	78.3	70.6	7.5	6.8
BICEPS DURATION (1st Burst)	157.5	132.4	3.28	3.62	1.34	1.48	161.7	135.5	153.1	126.2	8.6	9.3
BICEPS SILENT PERIOD	142.8	111.5	1.87	6.93	.76	2.83	145.0	122.0	140.1	101.9	4.9	20.1
TRICEPS MOTOR TIME(1st Burst)	73.7	54.1	3.37	5.58	1.38	2.28	77.9	61.5	68.4	45.8	9.5	15.7
TRICEPS MOTOR TIME(2nd Burst)	137.7	119.3	4.19	2.53	1.71	1.03	142.9	116.5	131.4	109.2	11.5	7.3
TRICEPS DURATION (2nd Burst)	110.1	82.2	6.20	2.77	2.53	1.13	117.2	85.9	102.9	78.0	14.3	7.9
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	7.0	20.3	5.90	5.39	2.41	2.20	17.5	26.3	.9	12.2	16.6	14.1
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	172.1	149.6	3.80	3.10	1.55	1.26	177.7	152.5	168.2	144.3	9.5	8.2
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	-11.0	-6.4	6.59	4.16	2.69	1.70	-3.6	1.0	-22.3	-10.0	18.7	11.0
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	72.6	63.3	3.62	3.20	1.48	1.30	77.8	69.3	67.7	60.2	10.1	9.1
MAXIMAL DISPLACEMENT	107.5	104.1	1.36	1.51	.39	.44	109.2	106.2	105.7	102.0	3.5	4.2
SLOPE FOR BICEPS(1B) EMG	4.2	1.4	.21	.10	.06	.03	4.4	1.5	3.9	1.3	0.5	0.2
SLOPE FOR TRICEPS(2B) EMG	9.4	2.8	1.95	.66	.56	.19	12.2	3.7	7.3	2.2	4.9	1.5
BICEPS(1B)/TRICEPS(2B) EMG	59.2	64.9	4.44	5.08	1.81	2.08	67.5	71.8	54.3	56.2	13.2	15.6
BICEPS EMG/TRICEPS EMG	5.6	4.3	1.56	.35	.45	.10	7.7	4.8	4.1	3.9	3.6	0.2

*Displacement is expressed in degrees, all other measures are expressed in milliseconds.

TABLE 16

MEANS, STANDARD DEVIATIONS, STANDARD ERRORS, MAXIMUMS, MINIMUMS, AND RANGES FOR THE CRITERION MEASURES OVER DAYS 5 - 10 UNDER LOAD CONDITION 2, N = 24.*

	MEAN $\overline{X}$		STANDARD DEVIATION		STANDARD ERROR		MAXIMUM		MINIMUM		RANGE	
	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
MOVEMENT TIME	274.0	226.4	3.85	3.48	1.57	1.42	280.3	232.7	296.6	223.6	10.7	9.1
ACCELERATION TIME	194.1	164.9	3.41	2.57	1.39	1.05	198.1	169.5	188.2	162.5	9.9	7.0
TIME TO MAXIMAL ACCELERATION	90.8	69.4	6.20	2.76	2.53	1.13	100.4	72.6	81.3	65.9	19.1	6.7
BICEPS MOTOR TIME (1st Burst)	102.5	86.0	2.57	1.39	1.05	.57	105.6	87.9	99.5	84.2	6.1	3.7
BICEPS DURATION (1st Burst)	179.8	141.2	5.84	2.96	2.38	1.21	186.4	145.2	169.8	137.1	16.6	8.1
BICEPS SILENT PERIOD	152.7	151.7	5.47	4.94	2.23	2.02	158.0	159.8	143.7	145.5	14.3	14.3
TRICEPS MOTOR TIME(1st Burst)	82.0	67.5	3.50	2.34	1.43	.95	88.6	70.4	78.8	65.2	9.8	5.2
TRICEPS MOTOR TIME(2nd Burst)	155.1	137.4	2.89	3.69	1.18	1.51	159.8	142.1	152.2	131.7	7.6	10.4
TRICEPS DURATION (2nd Burst)	116.8	93.2	5.37	5.36	2.19	2.19	122.2	100.2	107.9	84.1	14.3	16.1
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	15.9	30.7	4.85	8.38	1.98	3.42	23.9	46.0	10.4	21.0	13.5	25.0
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	219.7	172.3	4.17	5.19	1.70	2.12	226.8	179.4	214.0	165.4	12.8	14.0
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	-28.0	-19.5	6.69	5.08	2.73	2.07	-20.3	-14.9	-38.1	-29.5	17.8	14.6
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	75.2	75.9	1.97	4.00	.81	1.63	78.4	79.9	73.2	68.9	5.2	11.0
MAXIMAL DISPLACEMENT	107.6	104.5	1.50	1.97	.43	.57	109.2	107.8	105.9	102.3	3.3	5.5
SLOPE FOR BICEPS(1B) EMG	4.3	1.5	.35	.11	.10	.03	4.8	1.6	3.8	1.3	1.0	0.3
SLOPE FOR TRICEPS(2B) EMG	9.2	3.4	.76	.89	.22	.27	10.1	5.1	8.3	2.6	1.8	2.5
BICEPS(1B)/TRICEPS(2B) EMG	65.5	67.1	9.19	17.56	3.75	7.17	75.2	84.8	53.5	46.3	21.7	38.5
BICEPS EMG/TRICEPS EMG	6.3	4.5	.91	.36	.26	.11	7.4	4.8	5.0	3.9	2.4	0.9

*Displacement is expressed in degrees, all other measures are expressed in milliseconds.

TABLE 17

MEANS, STANDARD DEVIATIONS, STANDARD ERRORS, MAXIMUMS, MINIMUMS, AND RANGES FOR THE CRITERION MEASURES DURING THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER DAYS 5 - 10, N = 24.*

	MEAN $\bar{X}$		STANDARD DEVIATION		STANDARD ERROR		MAXIMUM		MINIMUM		RANGE	
LOAD 0	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
MOVEMENT TIME (90°)	142.5	127.8	3.00	1.12	1.23	.46	146.5	129.4	139.0	126.5	7.5	2.9
ACCELERATION TIME	131.2	121.4	2.90	1.47	1.18	.60	134.8	123.0	127.8	118.7	7.0	4.3
TIME TO 2ND BICEPS BURST	173.3	139.1	4.07	3.53	1.66	1.44	178.9	142.2	169.2	133.1	9.7	9.1
TIME TO 2ND TRICEPS BURST	75.5	63.5	1.95	1.50	.79	.61	77.5	65.4	71.9	62.1	5.6	3.3
LOAD 1												
MOVEMENT TIME (90°)	160.3	139.6	3.55	1.61	1.45	.66	164.2	141.6	156.7	137.5	7.5	4.1
ACCELERATION TIME	143.5	129.6	1.61	1.68	.66	.69	145.2	131.2	141.8	126.5	3.4	4.7
TIME TO 2ND BICEPS BURST	193.9	146.4	3.05	5.38	1.24	2.20	198.8	152.7	191.0	139.3	7.8	13.4
TIME TO 2ND TRICEPS BURST	83.2	64.7	3.10	1.70	1.26	.69	87.6	67.0	78.8	62.3	8.8	4.7
LOAD 2												
MOVEMENT TIME (90°)	197.7	169.6	2.30	1.66	.94	.68	201.2	172.1	195.4	167.3	5.8	4.8
ACCELERATION TIME	165.0	148.7	1.96	1.10	.80	.45	168.6	149.8	163.2	146.6	5.4	3.2
TIME TO 2ND BICEPS BURST	237.9	173.2	8.21	3.95	3.35	1.61	250.7	176.6	227.0	166.1	23.7	10.5
TIME TO 2ND TRICEPS BURST	107.2	79.9	3.05	2.01	1.24	.82	112.4	82.1	104.6	76.6	7.8	5.5

*All measures are expressed in milliseconds.

were as fast as the men in the Wolcott investigation. The men, under Load 0, were faster than both Lagasse's and Wolcott's male subjects.

Baseline criterion measures, for the first ninety degrees of flexion, were submitted to reliability analysis of variance and repeated measures analysis of variance to ascertain the level of reliability and the presence of stability over the six baseline experimental days. Table 18 presents the results of the reliability analysis of variance. A summary of the repeated measures analysis of variance is presented in Table 19 (complete Tables are contained in Appendix E).

Non significant Days effects resulted for all criterion measures for the first ninety degrees of forearm flexion. Men and Women differed significantly in movement time, acceleration time, time to second biceps burst, and time to second triceps burst. Inertial loading analysis yielded significant overall, linear, and quadratic trends for all the criterion measures. The reliability coefficients ranged from $r = .77$ to $r = .96$ across all loads for the women and $r = .83$ to $r = .95$ across all loads for the men. Most acceptable levels of reliability and stability were established for the criterion measures over the first ninety degrees of forearm flexion.

Baseline criterion measures, for the movement to maximal displacement, were also submitted to reliablity analysis

TABLE 18

VARIANCE ESTIMATES AND INTRACLASS RELIABILITY COEFFICIENTS FOR THE CRITERION MEASURES FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER SIX EXPERIMENTAL DAYS, N = 24.

MEASURES	σ^2 DAYS		σ^2 TRIALS		σ^2 TRUE SCORE		R	
LOAD 0	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
MOVEMENT TIME (90°)	47.26	21.88	6.96	13.70	65.20	94.34	.89	.95
ACCELERATION TIME	52.38	21.01	30.19	13.38	37.53	64.85	.77	.93
TIME TO 2ND BICEPS BURST	399.75	362.75	90.11	84.50	1174.20	333.14	.94	.83
TIME TO 2ND TRICEPS BURST	113.49	49.56	28.82	34.62	198.17	149.67	.90	.93
LOAD 1								
MOVEMENT TIME (90°)	52.73	26.59	9.77	12.13	80.16	87.94	.89	.94
ACCELERATION TIME	29.32	33.38	63.03	6.11	56.01	53.67	.85	.90
TIME TO 2ND BICEPS BURST	377.13	398.21	63.68	38.72	1229.67	388.73	.95	.85
TIME TO 2ND TRICEPS BURST	135.69	52.17	22.05	29.36	184.05	134.92	.88	.92
LOAD 2								
MOVEMENT TIME (90°)	49.56	49.49	20.14	14.07	257.62	153.01	.96	.94
ACCELERATION TIME	66.62	21.48	43.33	16.24	151.47	45.78	.91	.90
TIME TO 2ND BICEPS BURST	993.27	600.48	166.92	287.90	2697.70	758.68	.94	.86
TIME TO 2ND TRICEPS BURST	91.80	62.19	42.54	38.59	348.73	171.23	.95	.93

TABLE 19

SUMMARY OF *F* RATIOS FOR GROUPS, DAYS, LOADS, AND TRIALS EFFECTS INCLUDING LINEAR, AND QUADRATIC COMPONENTS FOR THE CRITERION MEASURES FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER SIX EXPERIMENTAL DAYS, N = 24.***

MEASURES	GROUPS	DAYS	LOADS	TRIALS
MOVEMENT TIME (90°)	22.97**	2.01	648.58**	8.12
Linear		6.60	1234.52**	
Quadratic		.56	62.65**	
Cubic		2.13		
ACCELERATION TIME	16.85**	.34	252.81**	.93
Linear		.01	486.61**	
Quadratic		.00	19.02**	
Cubic		1.13		
TIME TO 2ND BICEPS BURST	14.66**	.72	98.18**	7.16*
Linear		.03	184.39**	
Quadratic		1.91	11.98**	
Cubic		.06		
TIME TO 2ND TRICEPS BURST	11.71**	.36	139.11**	7.23*
Linear		.57	246.11**	
Quadratic		.10	32.11**	
Cubic		.37		

* $p < .05$
**$p < .01$
***Complete Repeated Measures ANOVA tables are presented in Appendix E.

of variance. Tables 20, 21, and 22 present the results of the reliablilty analysis of variance. Table 23 presents a summary of the repeated measures analysis of variance (complete Tables are contained in Appendix E).

The reliability analysis revealed a range of $r = .48$ to $r = .93$ for the men and $r = .49$ to $r = .93$ for the women, under load condition 0. A range of $r = .71$ to $r = .97$ for the men and $r = .08$ to $r = .91$ for the women, under load condition 1. Under load condition 2, the range was $r = .53$ to $r = .95$ for the men and $r = .48$ to $r = .96$ for the women. Acceptable levels of reliability were established.

The repeated measures analysis yielded significant groups differences in movement time, acceleration time, first biceps motor time, first biceps burst duration, second triceps burst duration, slope for the first biceps burst EMG, and slope for the second triceps burst EMG. The overall Days effect was statistically significant for the second triceps burst motor time, first biceps burst to second triceps burst latency, second triceps burst to maximal acceleration, and second triceps burst to zero acceleration latency. Inspection of the single degree components presented in Table 23 reveals non-significant linear trends for all the previously cited criterion measures. Therefore, day-to-day individual variability was in evidence rather than a protracted stabilization period. The overall Loads effect was statistically significant for movement time,

TABLE 20

VARIANCE ESTIMATES AND INTRACLASS RELIABILITY COEFFICIENTS FOR THE CRITERION MEASURES TO MAXIMAL DISPLACEMENT OVER SIX EXPERIMENTAL DAYS, UNDER LOAD CONDITION 0, N = 24.*

MEASURES	σ^2 DAYS		σ^2 TRIALS		TRUE SCORE		R	
	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
MOVEMENT TIME	157.72	429.25	795.96	98.10	270.58	109.96	.79	.59
ACCELERATION TIME	149.64	220.39	118.11	64.15	42.51	101.02	.78	.71
TIME TO MAXIMAL ACCELERATION	138.89	75.09	75.85	74.19	64.18	86.53	.70	.84
BICEPS MOTOR TIME (1st Burst)	102.36	74.70	90.59	88.74	21.38	74.16	.49	.81
BICEPS DURATION (1st Burst)	75.59	191.63	552.98	325.04	145.24	296.32	.77	.86
BICEPS SILENT PERIOD	573.06	443.66	1172.66	662.40	1116.45	279.16	.87	.72
TRICEPS MOTOR TIME (1st Burst)	141.84	175.55	972.02	2487.80	834.66	2296.65	.91	.93
TRICEPS MOTOR TIME (2nd Burst)	46.95	184.50	645.19	130.58	72.33	60.76	.62	.62
TRICEPS DURATION (2nd Burst)	23.24	412.83	410.73	576.48	366.88	466.67	.93	.82
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	133.76	349.33	743.21	653.02	638.48	903.87	.91	.91
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	63.06	269.83	218.85	139.51	248.46	404.33	.92	.88
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	78.34	74.46	169.95	152.92	222.76	65.63	.91	.76
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	26.78	69.53	106.33	85.05	27.64	32.59	.73	.67
MAXIMAL DISPLACEMENT	49.96	24.07	26.50	12.52	26.96	22.01	.73	.82
SLOPE FOR BICEPS (1B) EMG	-.34	-2.11	3.60	8.03	.25	.50	.56	.53
SLOPE FOR TRICEPS (2B) EMG	-.38	-1.81	3.60	8.05	.25	.41	.56	.48
BICEPS (1B) EMG/TRICEPS (2B) EMG	2472.65	993.65	810.37	2346.10	2645.36	1156.80	.85	.80
TOTAL BICEPS EMG/TOTAL TRICEPS EMG	12.99	3.91	11.01	5.98	22.17	8.20	.89	.89

*Negative variance estimates were set to zero in the computation of intraclass reliability coefficients.

TABLE 21

VARIANCE ESTIMATES AND INTRACLASS RELIABILITY COEFFICIENTS FOR THE CRITERION MEASURES TO MAXIMAL DISPLACEMENT OVER SIX EXPERIMENTAL DAYS, UNDER LOAD CONDITION 1, N = 24.*

	σ^2 DAYS		σ^2 TRIALS		TRUE SCORE		R	
MEASURES	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
MOVEMENT TIME	376.50	36.49	84.41	87.79	430.60	209.77	.86	.95
ACCELERATION TIME	194.89	15.21	42.17	48.52	122.83	114.99	.78	.96
TIME TO MAXIMAL ACCELERATION	156.57	22.76	59.86	37.52	63.75	88.16	.68	.94
BICEPS MOTOR TIME (1st Burst)	~~1061.77~~ 36.33	34.02	~~467.33~~ 89.16	73.52	~~48.99~~ 26.74	72.49	~~.08~~ .71	.88
BICEPS DURATION (1st Burst)	299.39	110.87	378.69	370.75	163.31	274.71	.70	.87
BICEPS SILENT PERIOD	375.14	129.48	676.59	550.13	99.96	448.88	.50	.90
TRICEPS MOTOR TIME (1st Burst)	385.01	570.51	426.61	898.24	891.83	3179.33	.91	.96
TRICEPS MOTOR TIME (2nd Burst)	174.16	114.50	538.04	106.12	469.98	158.15	.89	.86
TRICEPS DURATION (2nd Burst)	340.70	-21.05	671.37	460.24	493.89	200.16	.84	.89
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	625.88	190.92	435.14	426.09	616.56	2142.31	.83	.97
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	627.56	86.73	567.64	128.61	283.71	423.95	.68	.95
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	820.12	103.58	530.23	81.21	348.15	112.33	.68	.84
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	397.05	61.58	495.60	66.63	338.26	33.48	.78	.71
MAXIMAL DISPLACMENT	439.64	22.00	13.46	14.67	61.06	31.60	.45	.88
SLOPE FOR BICEPS (1B) EMG	3.38	.12	1.80	.22	2.03	.16	.75	.83
SLOPE FOR TRICEPS (2B) EMG	181.81	4.50	34.70	10.58	67.33	6.34	.68	.83
BICEPS (1B) EMG/TRICEPS (2B) EMG	3460.98	1301.60	7276.95	1656.33	2403.62	2230.31	.71	.88
TOTAL BICEPS EMG/TOTAL TRICEPS EMG	15.06	.18	61.89	11.43	14.90	6.54	.71	.91

*Negative variance estimates were set to zero in the computation of intraclass reliability coefficients.

TABLE 22

VARIANCE ESTIMATES AND INTRACLASS RELIABILITY COEFFICIENTS FOR THE CRITERION MEASURES TO MAXIMAL DISPLACEMENT OVER SIX EXPERIMENTAL DAYS, UNDER LOAD CONDITION 2, N = 24.*

MEASURES	σ^2 DAYS		σ^2 TRIALS		TRUE SCORE		R	
	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
MOVEMENT TIME	192.35	144.57	121.83	84.04	869.03	201.84	.96	.88
ACCELERATION TIME	112.80	34.47	74.83	60.31	338.72	144.53	.94	.94
TIME TO MAXIMAL ACCELERATION	351.98	27.61	126.54	53.44	243.91	88.51	.79	.92
BICEPS MOTOR TIME (1st Burst)	138.42	31.30	107.10	76.57	27.11	58.61	.48	.86
BICEPS DURATION (1st Burst)	312.37	90.05	882.82	740.05	555.35	299.78	.85	.84
BICEPS SILENT PERIOD	116.69	123.42	1082.84	997.45	196.12	545.09	.71	.88
TRICEPS MOTOR TIME (1st Burst)	295.53	457.75	503.52	630.27	211.19	2117.10	.73	.95
TRICEPS MOTOR TIME (2nd Burst)	73.23	503.26	189.51	348.01	308.24	269.38	.93	.72
TRICEPS DURATION (2nd Burst)	304.47	292.33	575.82	812.51	557.10	255.06	.87	.73
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	190.43	477.00	460.74	536.59	87.82	1957.47	.61	.95
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	87.43	402.53	260.62	436.28	424.94	620.72	.94	.87
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY	271.64	384.28	197.87	380.76	175.83	117.92	.76	.58
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	48.51	305.30	118.38	351.82	48.19	110.05	.77	.61
MAXIMAL DISPLACEMENT	51.14	30.82	25.84	19.25	21.84	24.32	.69	.80
SLOPE FOR BICEPS (1B) EMG	.91	.07	1.72	.31	1.85	.23	.88	.89
SLOPE FOR TRICEPS (2B) EMG	272.43	18.32	25.48	22.94	91.41	4.92	.66	.53
BICEPS (1B) EMG/TRICEPS (2B) EMG	4163.76	2185.01	1854.84	4570.38	3955.78	5063.26	.83	.89
TOTAL BICEPS EMG/TOTAL TRICEPS EMG	5.65	5.12	14.68	6.95	22.59	7.50	.93	.86

*Negative variance estimates were set to zero in the computation of intraclass reliability coefficients.

TABLE 23

SUMMARY OF F RATIOS FOR GROUPS, DAYS, AND LOADS EFFECTS INCLUDING LINEAR, QUADRATIC, AND CUBIC COMPONENTS FOR THE CRITERION MEASURES TO MAXIMAL DISPLACEMENT OVER SIX EXPERIMENTAL DAYS, N = 24.***

MEASURES	GROUPS	DAYS	LOADS
MOVEMENT TIME	55.81*	.53	638.95**
Linear		.72	1229.81**
Quadratic		.39	48.10**
Cubic		.03	
ACCELERATION TIME	24.37*	1.52	50.09**
Linear		4.24	91.97**
Quadratic		.18	8.22*
Cubic		.34	
TIME TO MAXIMAL ACCELERATION	10.60	.49	.23
Linear		.50	.13
Quadratic		1.24	.32
Cubic		.03	
BICEPS (1B) MOTOR TIME	29.51*	.30	85.50**
Linear		.40	169.42**
Quadratic		.28	1.58
Cubic		.19	
BICEPS (1B) DURATION	1117.17**	.89	48.03**
Linear		.44	95.84**
Quadratic		.20	.22
Cubic		.13	
BICEPS SILENT PERIOD	4.82	.83	5.07
Linear		.44	3.73
Quadratic		2.34	6.41
Cubic		.58	

TABLE 23 (con't.)

MEASURES	GROUPS	DAYS	LOADS
TRICEPS (1B) MOTOR TIME	1.76	.92	1.56
Linear		.02	2.99
Quadratic		.49	.13
Cubic		2.59	
TRICEPS (2B) MOTOR TIME	14.24	7.92**	26.40**
Linear		8.91	52.80**
Quadratic		15.26**	.00
Cubic		13.14**	
TRICEPS (2B) DURATION	31.35*	.55	7.50*
Linear		.00	14.76*
Quadratic		.87	.24
Cubic		.00	
BICEPS (1B) TO TRICEPS (1B) LATENCY	.57	1.52	.36
Linear		1.97	.06
Quadratic		2.58	.67
Cubic		2.67	
BICEPS (1B) TO TRICEPS (2B) LATENCY	16.02	3.74*	20.93**
Linear		2.83	37.86**
Quadratic		6.90*	3.99
Cubic		3.81	
TRICEPS (2B) TO MAXIMAL ACCELERATION LATENCY	3.91	3.60*	10.12*
Linear		2.46	13.82*
Quadratic		7.92*	6.42
Cubic		3.97	
TRICEPS (2B) TO ZERO ACCELERATION LATENCY	1.36	4.07*	18.36**
Linear		3.35	36.35**
Quadratic		9.40*	.37
Cubic		5.61*	
MAXIMAL DISPLACEMENT	2.18	.81	.57
Linear		.34	.99
Quadratic		2.34	.14
Cubic		.04	

TABLE 23 (con't.)

MEASURES	GROUPS	DAYS	LOADS
SLOPE FOR BICEPS (1B) EMG	517.35**	1.50	.98
Linear		1.62	1.80
Quadratic		1.10	.16
Cubic		.04	
SLOPE FOR TRICEPS (2B) EMG	45.31*	.55	5.24
Linear		.06	8.49*
Quadratic		.61	1.99
Cubic		.12	
BICEPS (1B) EMG/TRICEPS (2B) EMG	.13	2.29	19.85**
Linear		8.25*	39.51**
Quadratic		.35	.19
Cubic		2.02	
TOTAL BICEPS EMG/TOTAL TRICEPS EMG	3.06	1.73	.78
Linear		.08	1.50
Quadratic		2.41	.07
Cubic		.61	
ACCURACY	2.93	.79	.49
Linear		.23	.88
Quadratic		2.43	.11
Cubic		.04	

* $p < .01$
** $p < .05$
***Complete Repeated Measures ANOVA tables are presented in Appendix E.

acceleration time, first biceps motor time, first biceps duration, second triceps motor time, second triceps duration first biceps burst to second triceps burst latency, second triceps burst to maximal acceleration latency, second triceps to zero acceleration latency, and the ratio between first biceps burst EMG and second triceps burst EMG.

Interrelationships between the criterion measures

Pearson product-moment intercorrelations were computed for all criterion measures to maximal displacement. Intercorrelations were computed using pooled observations over experimental days 5 through 10. The criterion measures were numbered vertically to correspond with the horizontal numerals. Tables 24, 25, and 26 present the correlations for Load condition 0, Load condition 1, and Load condition 2, respectively. Correlations which equaled or exceeded r = .50 were significant at the .05 level of confidence and correlations which equaled or exceeded r = .66 were significant at the .01 level of confidence. Acceleration time correlated very highly with movement time for both men and women, under all load conditions. These results contrasted with the near zero correlations reported by Wolcott (103), under all load conditions, for male subjects. Lagasse (53) reported correlations ranging from r = -.75 to r = -.80 between movement time and percent acceleration time.

Wolcott (103) reported non-significant correlations between movement time and isometric flexion and extension

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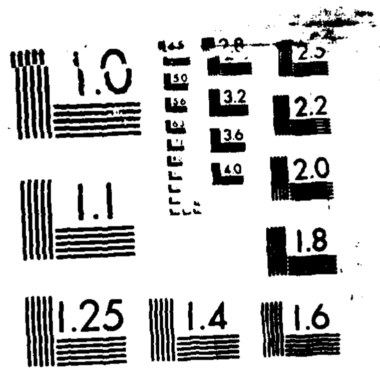

MICROCOPY RESOLUTION TEST CHART

TABLE 24

INTERCORRELATION MATRIX FOR THE CRITERION MEASURES TO MAXIMAL DISPLACEMENT USING POOLED VALUES OVER DAYS 5-10, UNDER LOAD CONDITION 0, N = 24.*

MEASURES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
											M E N										
MOVEMENT TIME (1)			.75	.35	.12	.36	-.10	.48	.48	-.18	-.77	.63	-.88	-.68	.28	.40	.25	-.45	.11	.21	-.05
ACCELERATION TIME (2)		.89		.85	.02	.48	-.03	.07	-.12	.08	-.55	.78	-.72	-.73	.17	-.09	-.36	-.68	-.43	.16	-.06
TIME TO MAX. ACCELERATION (3)		.24	.47		-.06	.42	-.14	-.28	-.43	.22	-.19	.64	-.33	-.57	-.03	-.33	-.62	-.58	-.69	-.10	-.16
FIRST BICEPS MOTOR TIME (4)		-.05	-.23	.20		.30	.04	.45	-.13	.33	.42	.60	-.28	-.30	.01	.20	.06	-.20	.02	.46	.16
FIRST BICEPS DURATION (5)		.60	.52	.44	.42		-.50	-.14	-.14	.69	.25	.67	-.61	-.78	.15	.07	-.31	-.14	-.21	.04	-.12
BICEPS SILENT PERIOD (6)		.33	.22	.32	.06	.20		.28	-.12	-.24	.03	-.05	.04	.24	-.44	-.16	-.21	-.14	-.13	.18	.22
FIRST TRICEPS MOTOR TIME (7)		-.07	-.27	-.09	.67	-.01	-.05		.38	-.15	.21	.33	-.41	-.10	.07	.40	.38	-.21	.30	.65	.45
SECOND TRICEPS MOTOR TIME (8)		.47	.11	-.12	.26	.39	.27	.24		-.56	-.56	-.17	-.28	-.04	.21	.69	.73	.34	.53	-.20	-.26
SECOND TRICEPS DURATION (9)		-.10	.01	.52	.22	.33	.07	.04	.16		.58	.38	-.15	-.39	-.25	-.12	-.52	-.19	-.46	.09	.05
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY (10)	W	-.19	-.18	-.06	-.04	.15	.02	-.63	-.02	-.04		-.13	.55	.28	-.40	-.17	-.33	.20	-.25	-.08	.05
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY (11)	O M	.77	.84	.46	.11	.49	.22	-.01	-.10	-.20	-.24		-.78	-.85	.03	.08	-.29	-.57	-.36	.32	-.02
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY (12)	E N	-.74	-.73	.16	.34	-.21	-.04	.21	.16	.51	.19	-.74		.87	-.11	-.33	-.10	.37	-.04	-.31	.03
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY (13)		-.41	-.49	-.02	.14	-.10	-.09	.11	.48	.55	.18	-.76	.80		.11	-.19	.12	.28	.18	-.08	.18
MAXIMAL DISPLACEMENT (14)		.74	.75	.10	-.18	.35	.21	.00	.30	-.06	-.38	.55	-.62	-.23		-.08	.18	-.17	.26	.24	.04
SLOPE FOR BICEPS(1B) EMG (15)		.25	.15	-.19	.22	.33	-.46	.30	-.05	-.26	-.19	.33	-.42	-.47	-.10		.69	.04	.32	-.10	-.22
SLOPE FOR TRICEPS(2B) EMG (16)		.73	.63	.13	.02	.43	.14	-.06	.14	-.32	.02	.71	-.70	-.64	.76	.60		.32	.82	.06	-.04
FIRST BICEPS BURST EMG/SECOND TRICEPS BURST EMG (17)		.34	.49	.47	-.36	.25	.54	-.63	-.26	-.18	.33	.46	-.33	-.47	.18	-.24	.42		.54	-.25	.01
BICEPS EMG/TRICEPS EMG (18)		.69	.58	.31	.10	.35	.48	-.09	.17	-.42	.11	.73	-.54	-.57	.23	.19	.84	.61		.28	.32
FLEXION M. V. C. (19)		-.35	-.35	-.32	.07	-.10	.09	-.15	-.49	-.20	.22	-.05	-.09	-.43	-.40	.16	-.11	.09	-.12		.84
EXTENSION M. V. C. (20)		-.07	-.11	-.57	-.35	-.01	-.13	-.39	-.32	-.43	.25	-.05	-.43	-.49	-.10	.35	-.18	.22	-.06	.71	

*LEFT HALF ARE FEMALE VALUES ±.50 = .05 Level of Confidence
RIGHT HALF ARE MALE VALUES ±.66 = .01 Level of Confidence

TABLE 25

INTERCORRELATION MATRIX FOR THE CRITERION MEASURES TO MAXIMAL DISPLACEMENT USING POOLED VALUES OVER DAYS 5-10, UNDER LOAD CONDITION 1, N = 24.

MEASURES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
											M E N										
MOVEMENT TIME (1)			.71	.44	.22	.31	-.34	.00	.39	.05	.03	.50	-.45	-.21	.65	.47	.38	-.51	.33	-.61	-.77
ACCELERATION TIME (2)		.90		.82	.25	.50	.00	-.12	-.29	.34	.16	.78	-.57	-.47	.51	.01	-.22	-.40	-.31	-.59	-.58
TIME TO MAX. ACCELERATION (3)		.42	.60		-.08	.10	.15	-.24	-.34	.41	.23	.49	-.12	-.29	.25	-.22	-.29	-.08	-.50	-.43	-.49
FIRST BICEPS MOTOR TIME (4)		-.13	-.30	-.28		.45	.14	.03	-.24	-.30	.12	.74	-.64	-.51	.04	.31	-.09	-.06	-.10	-.06	.17
FIRST BICEPS DURATION (5)		.52	.50	.19	.49		-.48	-.14	-.30	.20	.20	.60	-.68	-.43	.45	.27	-.09	-.07	-.07	-.12	-.17
BICEPS SILENT PERIOD (6)		.48	.60	.34	-.17	.31		.15	-.35	.02	-.13	.07	.14	.02	-.48	-.51	-.38	-.12	-.42	-.04	.32
FIRST TRICEPS MOTOR TIME (7)		-.06	-.15	-.17	.61	.42	-.08		.27	-.01	-.99	-.22	.12	.32	.30	-.21	.19	-.71	.26	.19	.12
SECOND TRICEPS MOTOR TIME (8)		.43	.24	.14	.19	.40	.20	.70		-.07	-.31	-.51	.43	.68	.26	.51	.84	-.32	.71	.12	-.21
SECOND TRICEPS DURATION (9)		-.04	.08	.44	.05	.29	.31	.47	.54		-.03	-.05	.20	.27	-.19	-.13	.04	-.14	-.28	.14	-.15
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY (10)	W	.04	.09	.12	-.44	-.36	.06	-.98	-.75	-.52		.33	-.22	-.40	-.30	.26	-.20	.70	-.27	-.20	-.10
FIRST BICEPS BURST TO SECOND	O																				
TRICEPS BURST LATENCY (11)	M	.54	.60	.24	-.07	.25	.24	-.58	-.50	-.54	.64		-.86	-.81	.27	.12	-.36	-.13	-.32	-.51	-.29
SECOND TRICEPS BURST TO MAXI-	E																				
MAL ACCELERATION LATENCY (12)	N	-.42	-.42	.13	.18	-.07	-.15	.65	.57	.73	-.69	-.91		.85	-.32	-.18	.29	.20	.02	.57	.33
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY (13)		-.08	-.11	.08	.16	.18	.07	.80	.83	.75	-.86	-.83	.89		-.05	.04	.51	-.18	.23	.58	.28
MAXIMAL DISPLACEMENT (14)		.69	.78	.30	-.24	.30	.23	-.04	.13	-.11	-.02	.52	-.43	-.13		.22	.15	-.57	.22	-.31	-.44
SLOPE FOR BICEPS(18) EMG (15)		.40	.23	-.04	.31	.42	.06	.22	.33	-.01	-.18	.10	-.10	.06	-.11		.72	.04	.60	.02	-.11
SLOPE FOR TRICEPS(20) EMG (16)		.73	.61	.09	.42	.73	.42	.17	.24	-.17	-.09	.59	-.46	-.19	.38	.54		-.14	.84	.10	-.21
FIRST BICEPS BURST EMG/SECOND TRICEPS BURST EMG (17)		.27	.40	.19	.23	.38	.30	-.07	-.29	-.28	.13	.64	-.47	-.40	.45	-.31	.56		-.19	.24	.27
BICEPS EMG/TRICEPS EMG (18)		.56	.51	.13	.38	.53	.18	.09	-.01	-.36	-.01	.67	-.51	-.34	.52	.09	.83	.86		-.09	-.25
FLEXION M.V.C. (19)		-.55	-.67	-.50	.43	.16	-.31	.37	.10	.24	-.31	-.56	.43	.31	-.73	.19	-.23	-.44	-.43		.84
EXTENSION M.V.C. (20)		-.76	-.84	-.69	.33	-.27	-.37	.54	.12	.14	-.53	-.80	.58	.48	-.50	-.15	-.49	-.40	-.48	.71	

LEFT HALF ARE FEMALE VALUES $\pm .50 = .05$ Level of Confidence
RIGHT HALF ARE MALE VALUES $\pm .66 = .01$ Level of Confidence

TABLE 26

INTERCORRELATION MATRIX FOR THE CRITERION MEASURES TO MAXIMAL DISPLACEMENT USING POOLED VALUES OVER DAYS 5-10, UNDER LOAD CONDITION 2, N = 24.

MEASURES		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
											M E N										
MOVEMENT TIME (1)			.64	.43	.16	.00	-.04	.54	.39	.19	-.54	.40	-.37	-.11	.46	.31	.35	-.77	.23	-.55	-.78
ACCELERATION TIME (2)		.93		.83	.23	.26	.34	.31	-.32	.37	-.27	.77	-.66	-.38	.28	-.12	-.29	-.65	-.44	-.46	-.42
TIME TO MAX. ACCELERATION (3)		.62	.75		.03	-.13	.52	.03	-.49	.16	-.02	.70	-.54	-.55	.08	-.37	-.42	-.40	-.54	-.53	-.48
FIRST BICEPS MOTOR TIME (4)		.11	-.03	-.14		.21	.19	.33	-.15	.13	-.13	.59	-.39	-.22	-.30	.41	.14	-.14	.09	-.03	.09
FIRST BICEPS DURATION (5)		.54	.52	.22	.28		-.56	-.11	-.32	.04	.16	.36	-.56	-.26	.30	.28	-.36	.06	-.28	-.04	.11
BICEPS SILENT PERIOD (6)		.56	.54	.55	.27	-.05		.11	-.25	.40	-.07	.25	.05	-.02	-.50	-.51	-.07	-.16	-.23	.00	.06
FIRST TRICEPS MOTOR TIME (7)		-.02	-.12	-.19	.74	.40	-.03		.57	.34	-.98	.02	.17	.47	.46	.14	.44	-.78	.42	-.01	-.12
SECOND TRICEPS MOTOR TIME (8)		.77	.53	.31	.15	.36	.42	.00		.15	-.63	-.62	.63	.76	.36	.29	.86	-.31	.83	.27	-.10
SECOND TRICEPS DURATION (9)		-.08	.05	.20	-.05	.13	-.27	-.04	-.11		-.33	.06	.10	.35	.02	-.13	.18	-.31	-.05	.24	.09
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY (10)	W	.11	.14	.17	-.36	-.36	.22	.89	.10	-.02		.10	-.26	-.54	-.55	-.06	-.43	.79	-.42	.00	.14
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY (11)	O M	.79	.84	.59	.78	.53	.53	.21	.29	-.04	-.04		-.91	-.78	-.10	.11	-.43	-.31	-.51	-.60	-.40
SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY (12)	E N	-.36	-.36	.27	-.20	-.40	.02	-.16	-.01	-.26	.09	-.54		.86	.01	-.23	.51	.21	.55	.70	.48
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY (13)		.16	.06	.10	-.17	-.01	.11	-.20	.62	.18	.16	-.37	.52		.23	-.08	.60	-.09	.60	.72	.49
MAXIMAL DISPLACEMENT (14)		.53	.62	.34	-.11	.41	.04	-.05	.15	-.28	-.14	.58	-.48	-.21		.08	.17	-.42	.25	-.05	-.23
SLOPE FOR BICEPS(1B) EMG (15)		.26	.10	-.32	.43	.24	.19	.36	.33	.06	-.22	.21	-.49	-.02	-.24		.35	-.20	.26	-.15	-.14
SLOPE FOR TRICEPS(2B) EMG (16)		.70	.58	.29	.59	.48	.55	.14	.57	.08	.20	.72	-.41	-.04	.05	.54		-.11	.93	.31	-.07
FIRST BICEPS BURST EMG/SECOND TRICEPS BURST EMG (17)		.44	.51	.63	.32	.42	.37	-.03	.12	.12	.26	.66	-.01	-.22	.30	-.32	.54		.02	.42	.45
BICEPS EMG/TRICEPS EMG (18)		.56	.45	.36	.57	.38	.63	.13	.39	-.34	.20	.67	-.24	-.19	.21	.10	.78	.71		.33	-.02
FLEXION M.V.C. (19)		.42	.53	.38	.08	.23	-.63	.37	-.08	.37	-.46	-.51	.31	.17	-.52	.08	-.24	-.22	-.39		.84
EXTENSION M.V.C. (20)		-.73	.77	-.56	.19	-.05	-.55	.51	-.46	-.04	-.58	-.58	.28	-.08	-.34	-.23	.54	-.29	-.34	.71	

LEFT HALF ARE FEMALE VALUES ± .50 = .05 Level of Confidence
RIGHT HALF ARE MALE VALUES ± .66 = .01 Level of Confidence

strength, except for load condition 3 (five times the natural moment of inertia) wherein isometric extension strength correlated signficantly with movement time (r = -60. Lagasse (53) reported correlations between flexion strength and movement time ranging from r = -.12 to r = -.34. He reported correlations between extension strength and movement time ranging from r = -.04 to r = -.20. In the present investigation, correlations between isometric expressed force and movement time, under Load condition 0, were low and non-significant. Under Load condition 1 (3 times the natural moment of inertia), isometric flexion force (r = .55 for the women and r = -.61 for the men) and isometric extension force (r = -.76 for the women and r = -.77 for the men) correlated significantly with movement time. Under Load condition 2 (7 times the natural moment of inertia), isometric extension force was highly correlated (r = -.73 for the women and r = -.78 for the men) with movement time. Correlations between isometric flexion force and movement time, under Load condition 2, were lower but still statistically significant.

Other criterion measures which correlated highly with movement time, for the women under Load 0, were: first biceps burst duration (r = .60), first biceps burst to second triceps burst latency (r = .77), second triceps burst to maximal acceleration latency (r = -.74), slope for the second triceps burst EMG (r = .73), and the ratio between the total biceps EMG and the total triceps EMG (r = .69). For the men, under Load 0, first biceps burst to first triceps burst latency (r = .63), second triceps burst to maximal acceleration latency (r = -.88), and second triceps burst to zero acceleration latency (r = -.68) correlated significantly with movement time.

Under Load 1, first biceps duration (r = .52), first biceps burst to second triceps burst latency (r = .54), slope for the second triceps burst EMG (r = .73), and the ratio between total biceps EMG and total triceps EMG (r = .56) also correlated significantly with movement time,for the women. For the men, under Load 1, first biceps burst to second triceps burst latency (r = .50) and the ratio between first biceps burst EMG and second triceps burst EMG (r = -.51) correlated significantly with movement time.

Under Load 2, other criterion measures which significantly correlated with movement time included: time to maximal acceleration (r = .62), first biceps duration (r = .54), biceps silent period (r = .56), second triceps motor time (r = .77), first biceps burst to second triceps burst latency (r = .79), slope for the second triceps burst EMG (r = .70), and the ratio between total biceps EMG and total triceps EMG (r = .56), for the women. For the men, under Load 2, first triceps motor time (r = .54), first biceps burst to first triceps burst latency (r = -.54), and the ratio between first biceps burst EMG and second triceps burst EMG correlated significantly with movement time.

Isometric strength assessments

The isometric strength measures assessed during the four practice days were submitted to repeated measures analysis of variance and reliability analysis of variance. It was considered prudent to ascertain the effects, if any, of speed of movement trials, resisted and unresisted, on the isometric strength measures. Table 27 is a summary of the significant sources of variance for the repeated measures ANOVA for isometric strength. Significant differences existed between groups for flexion and extension. The daily means for isometric strength measures are presented in Table 28. Although F.M.V.C. measures differed significantly from M.V.C. measures, the percent difference was not considered sufficient to require compensation. Therefore, maximum voluntary contraction force measures were used in the analysis of the experimental results.

The intraclass reliability coefficients were within a highly satisfactory range, $r = .86$ to $r = .98$ for the women and $r = .88$ to $r = .93$ for the men. The absence of a significant Days or practice effects was noted. One possible explanation is the level of physical activity enjoyed by all the subjects, maximal efforts were not unknown to them.

TABLE 27

SUMMARY OF REPEATED MEASURES ANALYSIS OF ISOMETRIC STRENGTH MEASURES OVER FOUR PRACTICE DAYS, N = 24.***

Source	Degrees of Freedom	F Ratio
Groups (G)	1	44.80**
Days (D)	3	.48
DG	3	.15
Pre (P)	1	159.72**
PD	3	2.60
PG	1	10.70**
PDG	3	.66
Flexion (F)	1	16.08**
FG	1	23.93**
FD	3	6.77**
FDG	3	.67
FP	1	2.47
FPG	1	.07
FPD	3	2.12
FPDG	3	2.86*
M.V.C. (M)	1	14.14**
MG	1	4.26
MD	3	.88
MDG	3	.50
MP	1	.01
MPG	1	.04
MPD	3	5.52**
MF	1	6.04*
MFG	1	7.72*
MFD	3	.21
Trials (T)	1	.09
TG	1	.00
TD	3	1.64
TDG	3	.17
TPD	3	.14
TPDG	3	2.81*
TF	1	.84
TM	1	1.69
TMG	1	.03
TMD	3	1.10

* $p < .01$
** $p < .05$
***Complete ANOVA table presented in Appendix E.

TABLE 28

MEAN VALUES OF FOUR TRIALS FOR ISOMETRIC STRENGTH, VARIANCE ESTIMATES, AND INTRACLASS RELIABILITY COEFFICIENTS OVER FOUR PRACTICE DAYS, N = 24.*

MEASURES	DAY 1		DAY 2		DAY 3		DAY 4	
FLEXION	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
M.V.C.	23.24	46.04	25.47	46.80	24.62	48.42	26.33	47.96
F.M.V.C.	24.76	44.91	26.41	45.76	25.70	47.64	26.68	48.07
EXTENSION								
M.V.C.	27.98	36.10	25.48	33.91	25.70	32.92	25.60	33.38
F.M.V.C.	28.84	37.92	25.97	34.50	26.67	34.44	26.69	34.42

	σ^2 DAYS		σ^2 TRIALS		σ^2 TRUE SCORE		R	
FLEXION	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN	WOMEN	MEN
M.V.C.	12.61	13.36	4.54	14.37	20.50	40.88	.86	.91
F.M.V.C.	10.81	11.56	6.13	13.18	19.72	47.18	.87	.93
EXTENSION								
M.V.C.	3.53	8.92	11.40	12.33	60.62	23.06	.97	.88
F.M.V.C.	3.24	10.28	10.48	12.71	66.24	26.99	.98	.89

*All daily means are expressed in pounds.

Analysis of the Experimental Conditions

Strength changes

The pre and post fatigue means for isometric flexion and extension expressed force are presented in Table 29. The percent expressed force decrement for flexion ranged from 20.5% to 26.4% for the men, and from 21.0% to 27.5% for the women, after the imposition of an agonist fatigue regimen. The percent expressed force decrement for extension ranged from .3% to 8.4% for the men, and from 1.8% to 20.8% for the women, after the imposition of an agonist fatigue regimen. After the imposition of an antagonist fatigue regimen, the percent expressed force decrement for extension ranged from 7.0% to 36.7%, for the men, and from 14.0% to 20.8%, for the women. The percent expressed force decrement for flexion ranged from 4.3% to 20.7%, for the men, and from 7.2% to 19.9%, for the women, after the imposition of antagonist fatigue regimens.

The unique fatigue regimen, designated as 5/5:0, produced inconsistant results, as presented in Table 29. The women, after the imposition of both 5/5:0 fatigue regimens, achieved a similar percent decrement in both agonist and antagonist musculature. The depth of the induced fatigue, after 5/5:0 exercise regimens, for the men, was at least three times greater in the agonist musculature than in the antagonist musculature. The attempt to induce relative fatigue in both agonist and antagonist musculature con-

TABLE 29

PRE AND POST FATIGUE REGIMENS MEANS AND PERCENT DIFFERENCES FOR EXPRESSED FORCE MEASURES, N = 24.

	FLEXION REGIMENS								
	5:5			5:10			5/5:0		
MEN	Pre	Post	Δ%	Pre	Post	Δ%	Pre	Post	Δ%
FLEXION	49.1	36.9	-24.8	53.0	39.0	-26.4	49.4	39.3	-20.5
EXTENSION	36.4	36.3	-.3	38.2	38.6	+1.0	35.8	32.8	-8.4
WOMEN									
FLEXION	29.5	21.4	-27.5	28.6	22.6	-21.0	30.2	23.0	-23.8
EXTENSION	27.9	28.4	+1.8	27.2	28.0	+2.9	27.4	21.7	-20.8

	EXTENSION REGIMENS								
	5:5			5:10			5/5:0		
MEN	Pre	Post	Δ%	Pre	Post	Δ%	Pre	Post	Δ%
FLEXION	51.3	47.0	-8.4	49.3	47.2	-4.3	51.7	41.0	-20.7
EXTENSION	38.4	24.3	-36.7	36.2	28.7	-20.7	38.8	36.1	-7.0
WOMEN									
FLEXION	27.5	25.4	-7.6	29.1	27.0	-7.2	29.6	23.7	-19.9
EXTENSION	26.9	21.3	-20.8	27.9	22.5	-19.4	27.9	24.0	-14.0

Δ = Differences

currently was not successful in the males. One possible explanation was the 30 percent difference between extension M.V.C. and flexion M.V.C., for the men, while the women differed by less than one percent.

The variance analysis of the fatigue regimens is presented in Table 30. Significant differences existed between the women and the men in their response to the fatigue regimens. Trial analysis revealed significant linear and cubic components, inspection of Figures 24, 25, 26, 27, 28, and 29 clearly support the statistical results. The percent decrements, presented in Table 29, in conjunction with the highly significant linear trends, reported in Table 30, established the existence of significant agonist and antagonist fatigue in both the women and the men.

Criterion measures

The pre and post fatigue regimen means and differences for the criterion measures to maximal displacement are presented in Tables 31, 32, and 33. The pre and post fatigue regimen means and differences for the criterion measures during the first ninety degrees of forearm flexion are presented in Table 34.

Movement time. The post fatigue analysis of variance for this criterion measure to maximal displacement is presented in Table 35. The variance analysis for movement time during the first ninety degrees of forearm flexion is presented in

TABLE 30

ANALYSIS OF VARIANCE FOR ISOMETRIC FATIGUE REGIMENS, INCLUDING LINEAR, QUADRATIC, AND CUBIC COMPONENTS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups(G)	1	172574.20	28.10**
S:G	22	6141.02	
Flexion(F)	1	65741.02	85.95**
FG	1	18861.65	24.66**
FS:G	22	764.77	
Rest Interval(I)	3	832.21	2.24
Linear	1	1127.89	3.03
Quadratic	1	1283.50	3.45
Cubic	1	85.24	.23
IG	3	145.43	.39
IS:G	66	372.19	
FI	3	136.85	.17
FIG	3	789.12	2.71
FIS:G	66	291.22	
Trials(T)	29	1008.36	67.14**
Linear	1	25340.49	1687.26**
Quadratic	1	3781.44	251.78**
Cubic	1	27.12	1.81
TG	29	83.93	5.59*
TS:G	638	15.02	
FT	29	10.12	1.32
FTG	29	36.71	4.81**
FTS:G	638	7.64	
IT	87	12.80	1.89**
ITG	87	12.22	1.81**
ITS:G	1914	6.76	
FIT	87	7.26	.92
FITG	87	4.39	.56
FITS:G	1914	7.91	

* $p < .05$
** $p < .01$

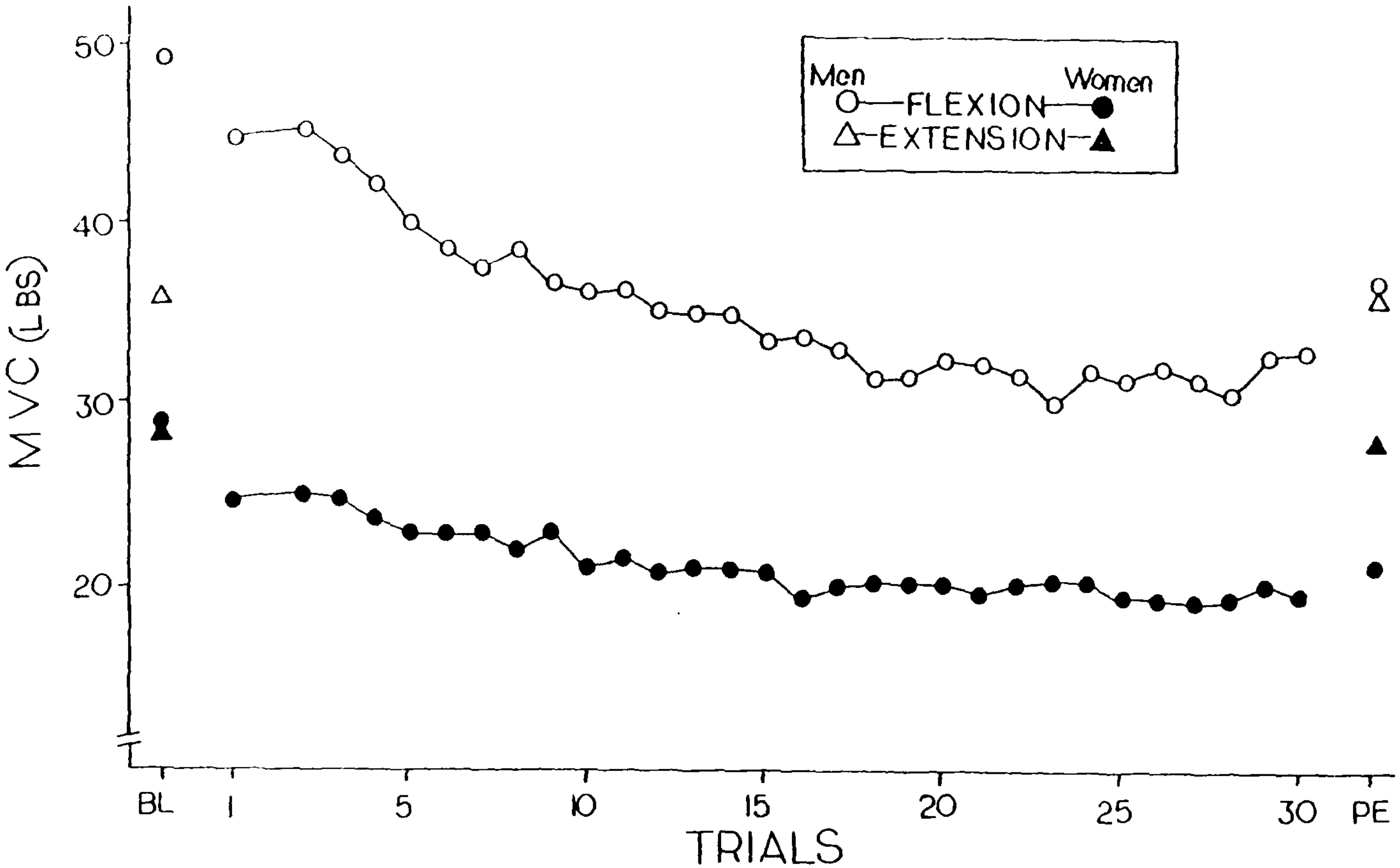

Fig. 24. Maximal Voluntary Isometric Muscular Force Means for Baseline Pre-Exercise (BL), 30-Trial 5:5 Flexion Exercise Regimen, and Post-Exercise (PE), N=24.

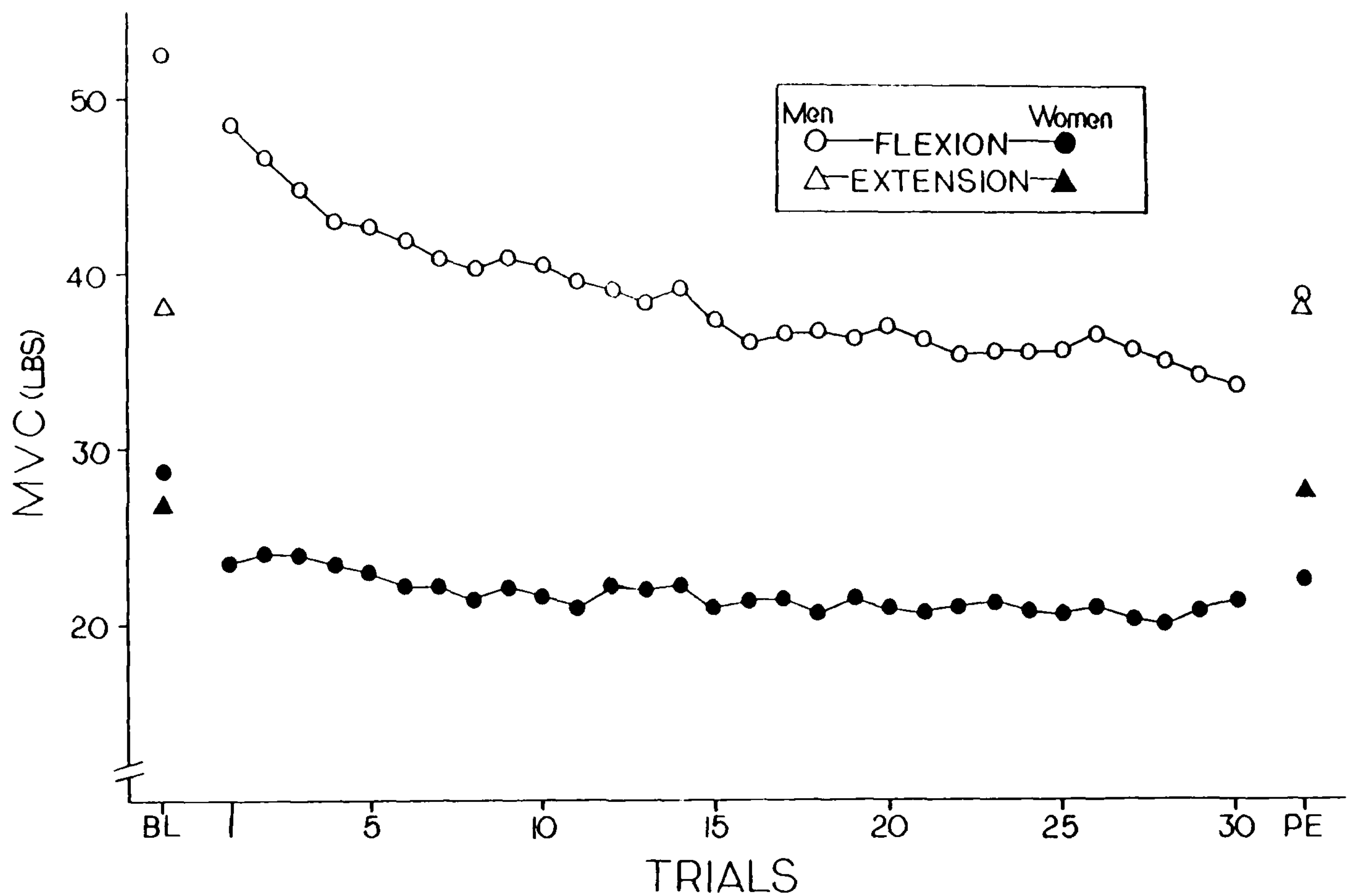

Fig. 25. Maximal Voluntary Isometric Muscular Force Means for Baseline Pre-Exercise (BL), 30-Trial 5:10 Flexion Exercise Regimen, and Post-Exercise (PE), N=24.

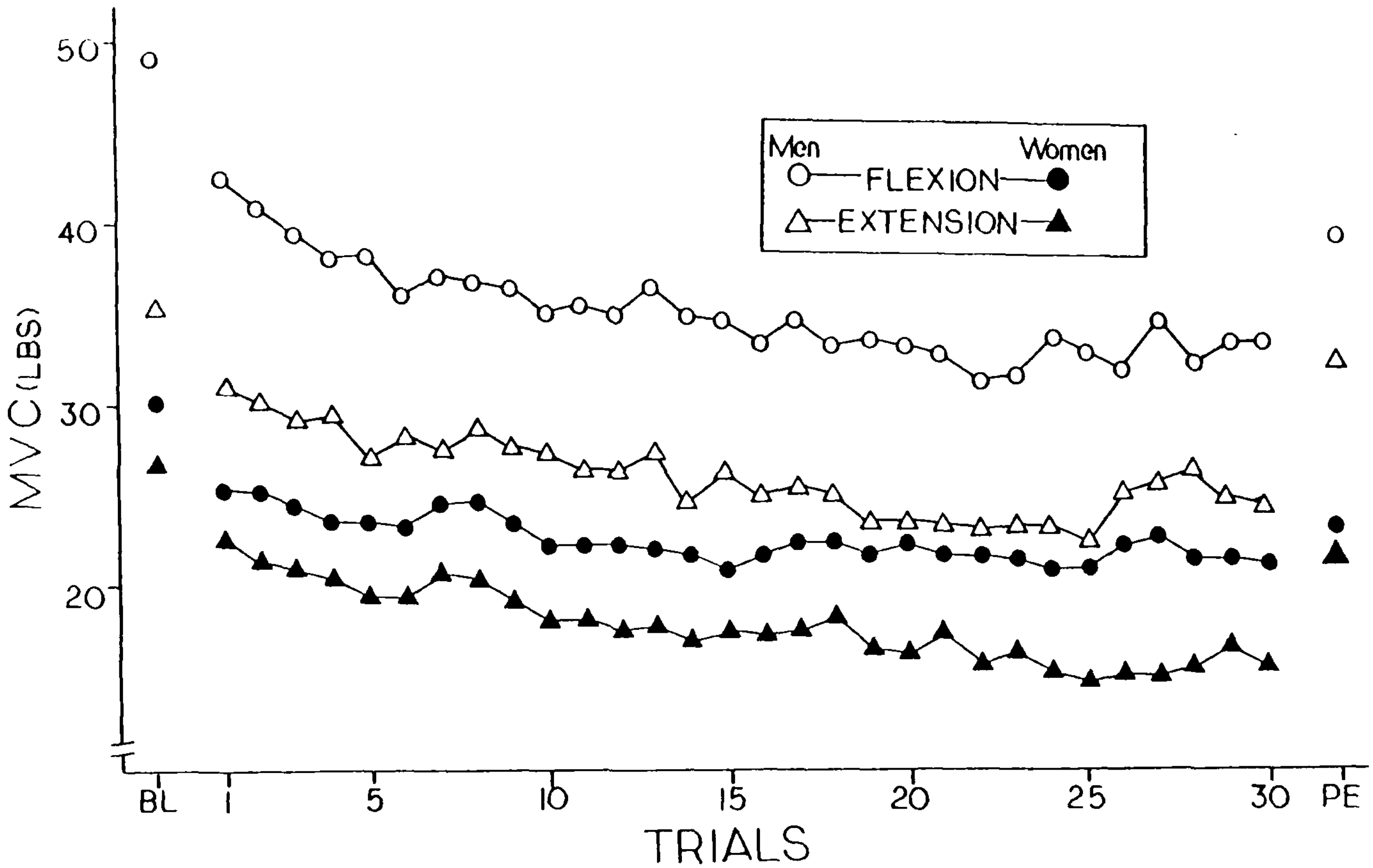

Fig. 26. Maximal Voluntary Isometric Muscular Force Means for Baseline Pre-Exercise (BL), 30-Trial 5/5:0 Flexion Exercise Regimen, and Post-Exercise (PE), N = 24.

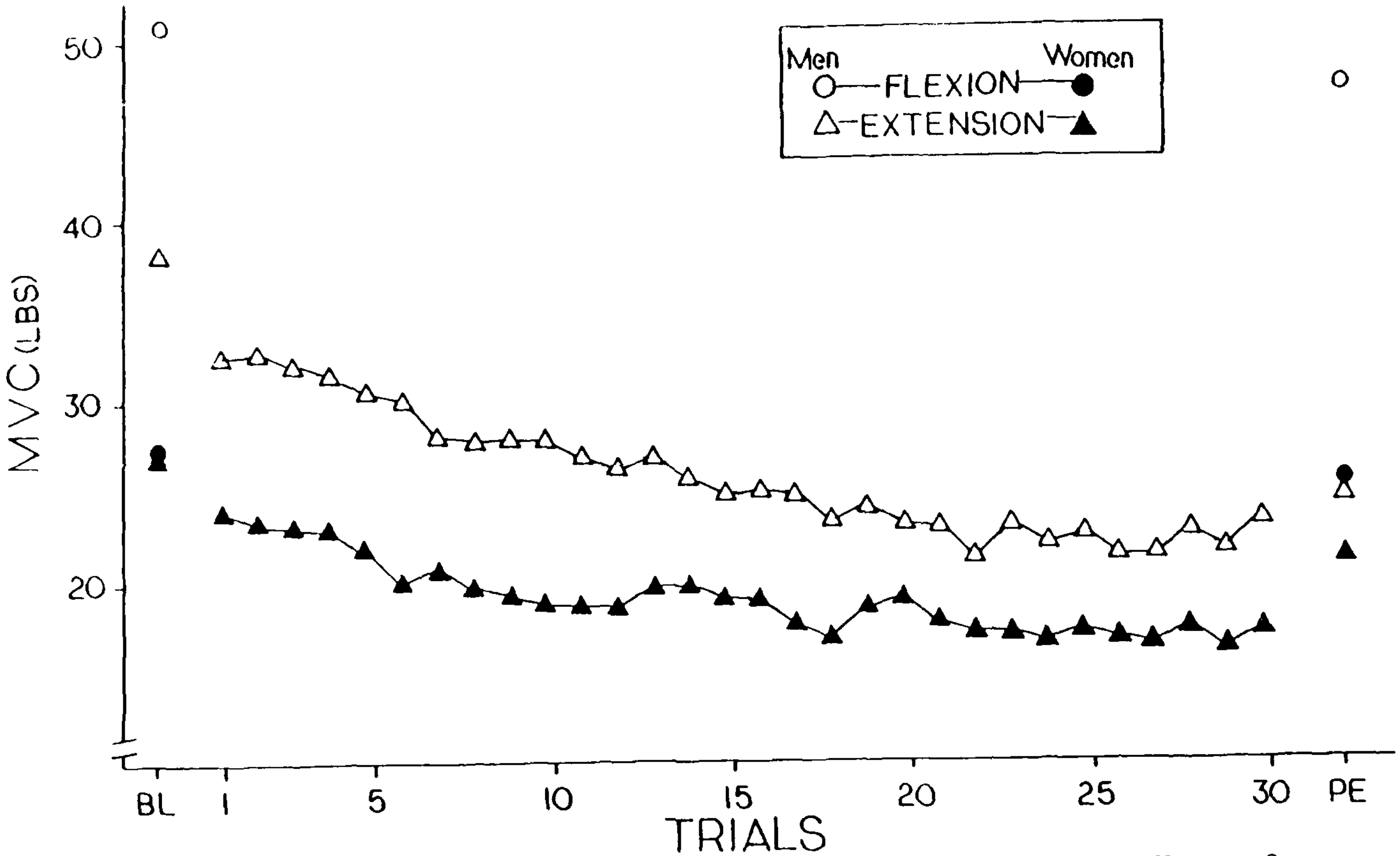

Fig. 27. Maximal Voluntary Isometric Muscular Force Means for Baseline Pre-Exercise (BL), 30-Trial 5:5 Extension Exercise Regimen, and Post-Exercise (PE), N=24.

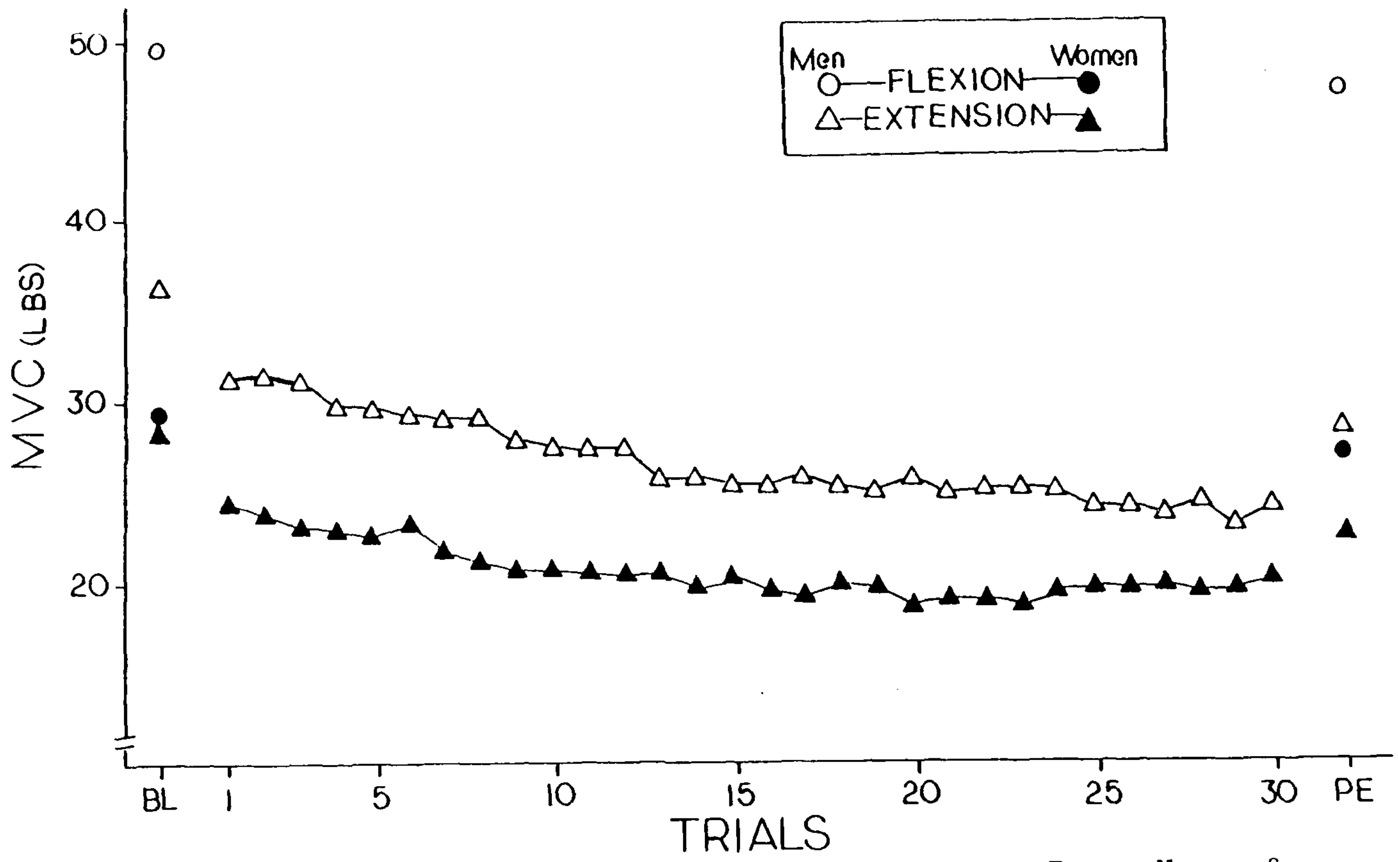

Fig. 28. Maximal Voluntary Isometric Muscular Force Means for Baseline Pre-Exercise (BL), 30-Trial 5:10 Extension Exercise Regimen, and Post-Exercise (PE), N=24.

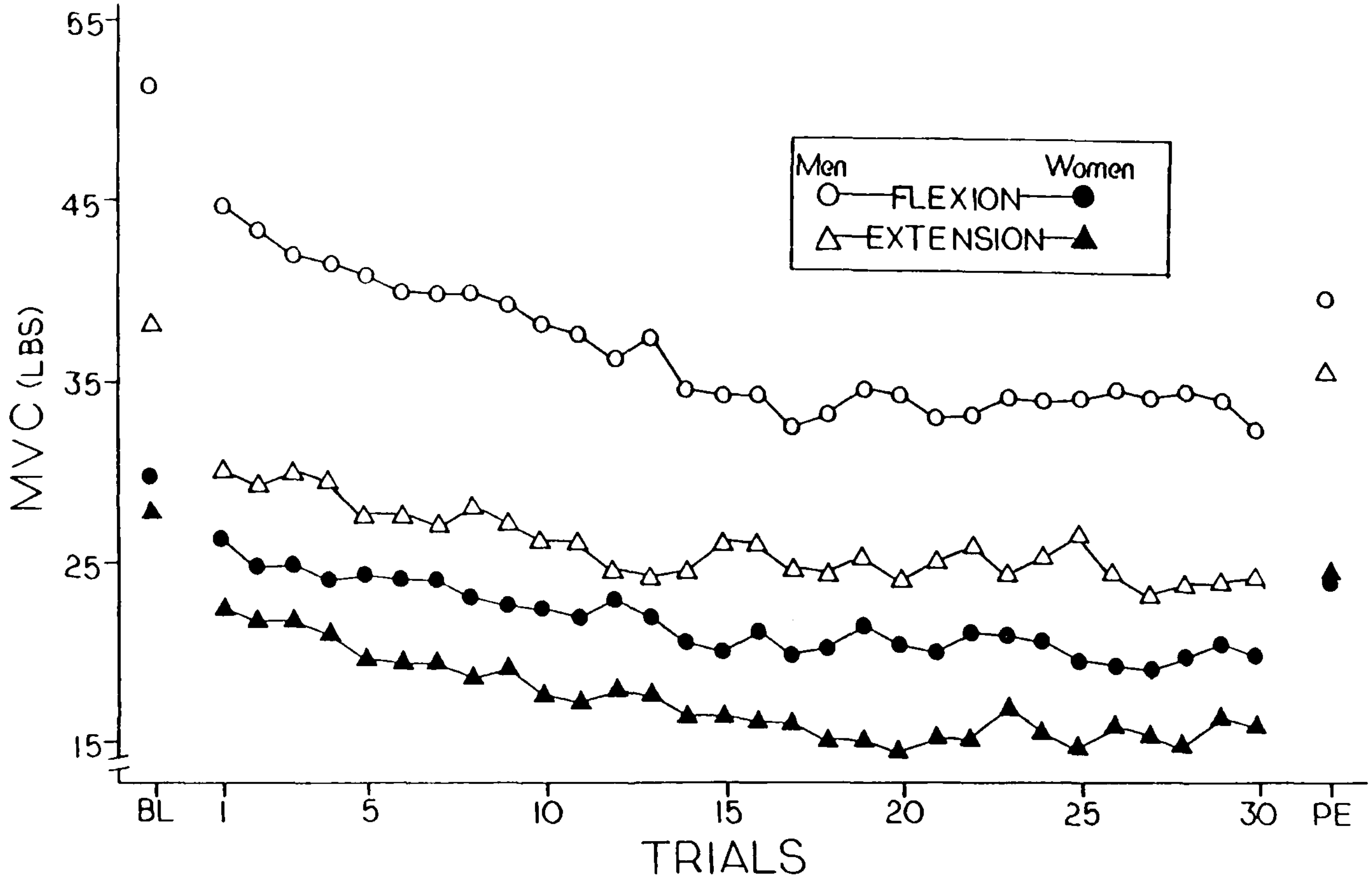

Fig. 29. Maximal Voluntary Isometric Muscular Force Means for Baseline Pre-Exercise (BL), 30-Trial 5/5:0 Extension Exercise Regimen, and Post-Exercise (PE), N = 24.

TABLE 31

PRE AND POST FATIGUE REGIMENS MEANS AND DIFFERENCES FOR THE CRITERION MEASURES UNDER LOAD CONDITION 0, N = 24.*

FATIGUE REGIMENS

	FLEXION									EXTENSION								
	5:5			5:10			5/5:0			5:5			5:10			5/5:0		
DEN	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**
MOVEMENT TIME	179	190	+11	180	192	+12	177	192	+15	178	180	+2	180	175	-5	181	186	+5
ACCELERATION TIME	139	145	+6	138	147	+9	137	146	+9	137	137	0	139	135	-4	143	144	+1
TIME TO MAX. ACCELERATION	80	79	-1	78	84	+6	78	85	+7	80	78	-2	79	79	0	83	87	+4
BICEPS MOTOR TIME (1-B)	-60	-64	-4	-61	-62	-1	-63	-60	+3	-60	-58	+2	-61	-64	-3	-63	-58	+5
BICEPS (1-B) DURATION	115	124	+9	120	119	-1	123	118	-5	117	111	-6	118	117	-1	122	113	-9
BICEPS SILENT PERIOD	119	129	+10	114	123	+9	115	131	+16	113	131	+18	112	122	+10	128	133	+5
TRICEPS MOTOR TIME (1-B)	-43	-48	-5	-43	-51	-8	-42	-37	+5	-42	-59	-17	-46	-56	-10	-46	-46	0
TRICEPS MOTOR TIME (2-B)	96	92	-4	100	99	-1	90	95	+5	98	96	-2	97	95	-2	94	93	-1
TRICEPS (2-B) DURATION	86	67	-19	88	81	-7	71	74	+3	82	87	+5	78	78	0	84	83	-1
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	28	29	+1	24	34	+10	28	34	+12	21	40	+19	26	34	+8	25	49	+24
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	140	158	+18	137	153	+16	145	153	+8	136	138	+2	140	138	+2	145	148	+3
SECOND TRICEPS BURST TO MAX. ACCELERATION LATENCY	-3	-19	-16	-2	-9	-7	-8	-13	-5	-1	-6	-5	-3	0	+3	-4	-7	-3
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	56	47	-9	58	54	-4	50	49	-1	57	53	-6	56	55	-1	57	50	-7
MAXIMAL DISPLACEMENT	102	101	-1	104	102	-2	102	103	+1	99	101	+2	102	103	+1	102	101	-1
SLOPE FOR BICEPS(1B) EMG	1	1	0	1	2	+1	1	1	0	1	1	0	1	1	0	1	1	0
SLOPE FOR TRICEPS(1B) EMG	2	2	0	2	2	0	2	2	0	2	2	0	1	2	+1	1	2	+1
BICEPS(1B)/TRICEPS(2B)	43	36	-7	43	29	-14	37	51	+14	41	35	-6	44	41	-3	39	49	+10
BICEPS EMG/TRICEPS EMG	3	4	+1	4	2	-2	3	4	+1	3	3	0	3	4	+1	3	3	0

TABLE 11 (Con't.)

	FATIGUE REGIMENS																	
	FLEXION									EXTENSION								
	5:5			5:10			5/5:0			5:5			5:10			5/5:0		
WOMEN	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**
MOVEMENT TIME	200	218	+18	201	217	+16	200	215	+15	206	211	+5	205	192	-13	207	219	+12
ACCELERATION TIME	149	164	+15	153	162	+9	152	159	+7	154	155	+1	153	143	-10	151	164	+13
TIME TO MAX. ACCELERATION	72	86	+14	80	87	+7	80	86	+6	78	87	+9	75	77	+2	80	87	+7
BICEPS MOTOR TIME (1-B)	-74	-73	+1	-69	-69	0	-73	-69	+4	-73	-71	+2	-72	-71	+1	-69	-69	0
BICEPS (1-B) DURATION	137	144	+7	133	137	+4	137	133	-4	134	135	+1	134	136	+2	130	137	+7
BICEPS SILENT PERIOD	156	167	+11	155	152	-3	159	165	+6	154	158	+4	161	141	-20	156	160	+4
TRICEPS MOTOR TIME (1-B)	-55	-55	0	-50	-51	-1	-58	-52	+6	-58	-64	-6	-60	-74	-14	-48	-66	-18
TRICEPS MOTOR TIME (2-B)	110	105	-5	110	105	-5	104	105	+1	110	112	+2	115	107	-8	110	105	-5
TRICEPS (2-B) DURATION	82	84	+2	84	78	-6	79	84	+5	85	99	+14	86	92	+6	83	85	+2
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	21	17	-4	16	17	+1	8	16	+8	16	8	-8	14	15	+1	19	8	-11
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	163	182	+19	156	178	+22	165	174	+9	164	166	+2	157	157	0	162	179	+17
SECOND TRICEPS BURST TO MAX. ACCELERATION LATENCY	-18	-27	-9	-12	-25	-13	-17	-18	-1	-18	-12	+6	-15	-8	+7	-17	-28	-11
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	59	51	-8	62	50	-12	55	50	-5	59	56	-3	62	57	-5	54	51	-3
MAXIMAL DISPLACEMENT	105	107	+2	107	105	-2	108	110	+2	106	105	-1	108	104	-4	109	106	-3
SLOPE FOR BICEPS(1B) EMG	4	4	0	4	4	0	4	4	0	3	4	+1	3	5	+2	3	4	+1
SLOPE FOR TRICEPS(2B) EMG	5	4	-1	5	5	0	6	5	-1	5	9	+4	6	10	+4	6	7	+1
BICEPS(1B)/TRICEPS(2B) EMG	40	39	-1	41	57	+16	32	41	+9	48	54	+6	41	51	+10	49	35	-14
BICEPS EMG/TRICEPS EMG	4	4	0	4	5	+1	5	4	-1	5	6	+1	5	5	0	5	5	0

*Maximal Displacement is expressed in degrees, all other measures are expressed in milliseconds. Negative values indicate time prior to the initiation of movement.
**Δ Differences

TABLE 32

PRE AND POST FATIGUE REGIMENS MEANS AND DIFFERENCES FOR THE CRITERION MEASURES UNDER LOAD CONDITION 1, N = 24.*

	FATIGUE REGIMENS																	
	FLEXION									EXTENSION								
	5:5			5:10			5/5:0			5:5			5:10			5/5:0		
MEN	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**
MOVEMENT TIME	193	192	-1	191	196	+5	192	195	+3	192	182	-10	188	178	-10	186	191	+5
ACCELERATION TIME	142	141	-1	142	142	0	143	142	-1	142	134	-8	141	133	-8	140	140	0
TIME TO MAX. ACCELERATION	72	66	-6	73	69	-4	74	70	-4	70	66	-4	72	68	-4	72	70	-2
BICEPS MOTOR TIME (1-B)	-74	-81	-7	-71	-82	-11	-76	-82	-6	-72	-78	-6	-77	-81	-4	-77	-82	-5
BICEPS (1-B) DURATION	115	127	+12	120	130	+10	123	117	-6	117	121	+4	118	126	+8	122	131	+9
BICEPS SILENT PERIOD	107	131	+24	110	123	+13	122	144	+22	102	135	+33	111	136	+25	116	131	+15
TRICEPS MOTOR TIME (1-B)	-61	-74	-13	-54	-75	-21	-50	-68	-18	-45	-62	-17	-57	-65	-8	-56	-78	-22
TRICEPS MOTOR TIME (2-B)	112	115	+3	110	108	-2	112	116	+4	112	118	+6	116	114	-2	109	114	+5
TRICEPS (2-B) DURATION	86	87	+1	88	84	-4	71	87	+16	82	97	+15	78	95	+17	84	89	+5
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	12	7	-5	16	7	-9	26	14	-12	26	16	-10	20	16	-4	21	4	-17
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	153	156	+3	148	166	+18	152	160	+8	150	140	-10	144	143	-1	151	156	+6
SECOND TRICEPS BURST TO MAX. ACCELERATION LATENCY	-10	-11	-1	-9	-19	-10	-6	-9	-3	-10	1	+11	1	2	+1	-5	-7	-2
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	61	64	+3	60	54	-6	63	63	0	62	70	+8	69	68	-1	64	63	-1
MAXIMAL DISPLACEMENT	106	102	-4	103	102	-1	105	104	-1	102	100	-2	104	100	-4	104	102	-2
SLOPE FOR BICEPS(1B) EMG	1	2	+1	1	2	+1	1	2	+1	2	2	0	1	1	0	1	2	+1
SLOPE FOR TRICEPS(2B) EMG	2	6	+4	3	3	0	2	4	+2	3	4	+1	4	4	0	2	4	+2
BICEPS(1B)/TRICEPS(2B) EMG	56	60	+4	65	62	-3	67	49	-18	65	73	+8	64	64	0	75	59	-13
BICEPS EMG/TRICEPS EMG	4	4	0	4	3	-1	4	4	0	4	3	-1	5	5	0	5	3	-2

TABLE 32 (con't.)

	FATIGUE REGIMENS																	
	FLEXION									EXTENSION								
	5:5			5:10			5/5:0			5:5			5:10			5/5:0		
WOMEN	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**
MOVEMENT TIME	227	228	+1	232	226	-6	231	226	-5	234	222	-12	229	209	-20	231	227	-4
ACCELERATION TIME	162	164	+2	166	163	-3	167	164	-3	169	156	-13	161	149	-12	168	165	-3
TIME TO MAX. ACCELERATION	79	77	-2	85	84	-1	78	76	-2	87	74	-13	83	74	-9	80	76	-4
BICEPS MOTOR TIME (1-B)	-86	-91	-5	-80	-89	-9	-81	-90	-9	-80	-91	-11	-84	-93	-9	-78	-90	-12
BICEPS (1-B) DURATION	161	163	+1	153	150	-3	160	151	-9	158	159	+1	154	144	-10	158	155	-3
BICEPS SILENT PERIOD	145	144	-1	144	131	-13	144	141	-3	141	138	-3	140	145	+5	143	137	-6
TRICEPS MOTOR TIME (1-B)	-68	-69	-1	-74	-71	+3	-73	-82	-9	-72	-80	-8	-78	-89	-11	-76	-71	+5
TRICEPS MOTOR TIME (2-B)	137	126	-11	135	132	-3	131	134	+3	143	141	-2	142	142	0	138	129	-9
TRICEPS (2-B) DURATION	108	105	-3	103	118	+15	103	112	+9	116	131	+15	117	136	+19	113	114	+1
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	17	22	+5	6	18	+12	8	8	0	8	11	+3	1	4	+3	2	19	+17
SECOND TRICEPS BURST TO MAX. ACCELERATION LATENCY	-11	-26	-15	-12	-10	+2	-22	-15	+7	-4	-7	-3	-4	7	+11	-13	-22	-9
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	73	61	-12	69	70	+1	68	72	+4	78	74	-4	74	82	+8	74	67	-7
MAXIMAL DISPLACEMENT	108	106	-2	109	106	-3	108	106	-2	106	104	-2	107	103	-4	106	96	-10
SLOPE FOR BICEPS(1B) EMG	4	5	+1	4	5	+1	4	5	+1	4	4	0	4	4	0	4	5	+1
SLOPE FOR TRICEPS(2B) EMG	8	9	+1	7	12	+5	7	12	+5	11	18	+7	10	19	+9	12	15	+3
BICEPS(1B)/TRICEPS(2B) EMG	59	73	+14	68	67	-1	58	67	+19	58	91	+33	58	75	+17	54	72	+18
BICEPS EMG/TRICEPS EMG	14	6	-8	4	5	+1	4	6	+2	8	7	-1	4	8	+4	7	7	0

*Maximal Displacement is expressed in degrees, all other measures are expressed in milliseconds. Negative measures indicate time prior to the initiation of movement.

**Δ Differences

TABLE 33

PRE AND POST FATIGUE REGIMENS MEANS AND DIFFERENCES FOR THE CRITERION MEASURES UNDER LOAD CONDITION 2, N = 24.*

	FATIGUE REGIMENS																	
	F L E X I O N									E X T E N S I O N								
	5:5			5:10			5/5:0			5:5			5:10			5/5:0		
MEN	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**
MOVEMENT TIME	227	253	+26	224	251	+27	233	262	+29	224	242	+18	224	241	+18	227	250	+23
ACCELERATION TIME	164	175	+11	163	180	+17	169	180	+11	164	170	+6	163	167	+4	166	177	+11
TIME TO MAX. ACCELERATION	66	77	+11	69	82	+13	73	84	+11	67	77	+10	70	79	+9	72	83	+11
BICEPS MOTOR TIME (1-B)	-86	-97	-11	-87	-92	-5	-85	-93	-8	-86	-88	-2	-84	-88	-4	-88	-92	-4
BICEPS (1-B) DURATION	140	162	+22	140	168	+28	141	149	+8	145	157	+12	137	151	+14	144	162	+18
BICEPS SILENT PERIOD	154	152	-2	146	133	-13	160	148	-12	150	149	-1	149	138	-11	152	145	-7
TRICEPS MOTOR TIME (1-B)	-66	-56	+10	-70	-47	+23	-70	-65	+5	-65	-64	+1	-65	-60	+5	-68	-56	+12
TRICEPS MOTOR TIME (2-B)	132	144	+12	137	141	+4	142	155	+13	140	150	+10	139	152	+13	135	145	+10
TRICEPS (2-B) DURATION	84	88	+4	94	105	+11	100	105	+5	93	114	+21	91	112	+11	96	112	+16
FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY	46	43	-3	29	43	+14	28	31	+3	21	18	-3	32	27	-5	28	45	+17
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	179	204	+25	171	201	+30	173	199	+26	168	179	+11	165	173	+8	177	193	+16
SECOND TRICEPS BURST TO MAX. ACCELERATION LATENCY	-29	-31	-2	-18	-28	-10	-18	-24	-6	-17	-16	+1	-15	-10	+5	-19	-22	-3
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	69	67	-2	75	69	-6	79	73	-6	80	78	-2	78	78	0	75	72	-3
MAXIMAL DISPLACEMENT	105	102	-3	102	103	+1	108	106	-2	103	103	0	105	106	+1	104	105	+1
SLOPE FOR BICEPS(1B) EMG	1	2	+1	2	2	0	1	2	+1	2	2	0	1	2	+1	2	2	0
SLOPE FOR TRICEPS(2B) EMG	3	4	+1	3	4	+1	3	4	+1	5	4	-1	4	4	0	3	5	+2
BICEPS(1B)/TRICEPS(2B) EMG	79	72	-7	51	71	+20	85	88	+3	85	74	-11	58	70	+12	46	91	+45
BICEPS EMG/TRICEPS EMG	5	6	+1	4	7	+3	4	5	+1	5	4	-1	5	5	0	5	7	+2

TABLE 33 (con't.)

WOMEN	FLEXION 5:5 Pre	Post	Δ**	5:10 Pre	Post	Δ**	5/5:0 Pre	Post	Δ**	EXTENSION 5:5 Pre	Post	Δ**	5:10 Pre	Post	Δ**	5/5:0 Pre	Post	Δ**
MOVEMENT TIME	272	293	+21	277	297	+20	274	290	+16	280	286	+6	270	262	-8	272	296	+24
ACCELERATION TIME	194	200	+6	198	199	+1	195	195	0	197	191	-6	188	182	-6	194	197	+3
TIME TO MAX. ACCELERATION	91	94	+3	100	100	0	90	84	-6	93	91	-2	89	88	-1	81	88	+7
BICEPS MOTOR TIME (1-B)	-102	-105	-3	-99	-105	-6	-100	-104	-4	-105	-106	-1	-106	-106	0	-103	-105	-2
BICEPS (1-B) DURATION	177	191	+14	179	183	+4	184	189	+5	186	199	+4	170	172	+2	182	171	-3
BICEPS SILENT PERIOD	158	158	0	157	159	+2	144	147	+3	151	155	+4	156	153	-3	151	166	+15
TRICEPS MOTOR TIME (1-B)	-83	-94	-11	-80	-83	-3	-81	-95	-14	-81	-101	-20	-89	-115	-26	-79	-104	-25
TRICEPS MOTOR TIME (2-B)	152	159	+7	155	163	+8	154	165	+11	157	174	+17	160	160	0	153	167	+14
TRICEPS (2-B) DURATION	120	124	+4	108	120	+12	122	122	0	113	144	+31	120	127	+7	119	133	+14
FIRST BICEPS TO FIRST TRICEPS BURST LATENCY	19	11	-8	15	21	-6	10	9	-1	15	5	-10	12	-10	-22	24	8	-16
FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY	220	237	+17	219	238	+19	218	228	+10	227	217	-10	214	205	-9	220	232	+12
SECOND TRICEPS BURST TO MAX. ACCELERATION LATENCY	-29	-41	-12	-21	-34	-13	-30	-41	-11	-30	-21	+9	-20	-13	+7	-38	-37	+1
SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY	74	66	-8	77	67	-10	75	70	-5	73	78	+5	78	80	+2	74	68	-6
MAXIMAL DISPLACEMENT	109	110	+1	109	106	-3	109	108	-1	106	106	0	106	104	-2	107	106	-1
SLOPE FOR BICEPS(1B) EMG	4	5	+1	4	5	+1	5	5	0	5	4	-1	4	4	0	4	5	+1
SLOPE FOR TRICEPS(2B) EMG	18	12	-6	8	11	+3	9	10	+1	10	19	+9	10	12	+2	10	17	+7
BICEPS(1B)/TRICEPS(2B) EMG	59	66	+6	67	72	+5	77	78	+1	63	61	-2	54	48	-6	75	73	-2
BICEPS EMG/TRICEPS EMG	6	8	+2	6	8	+2	5	6	+1	7	8	+1	6	6	0	7	4	-3

*Maximal Displacement is expressed in degrees, all other measures are expressed in milliseconds. Negative measures indicate time prior to the initiation of movement

**Δ Differences

TABLE 14

PRE AND POST FATIGUE REGIMENS MEANS AND DIFFERENCES FOR THE CRITERION MEASURES DURING THE FIRST NINETY DEGREES OF FOREARM FLEXION, UNDER ALL LOAD CONDITIONS, N = 24.*

	FATIGUE REGIMENS																	
	FLEXION									EXTENSION								
MEN	5:5			5:10			5/5:0			5:5			5:10			5/5:0		
LOAD 0	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**	Pre	Post	Δ**
MOVEMENT TIME (90°)	127	140	+13	127	139	+12	128	138	+10	128	130	+2	129	125	-4	129	139	+10
ACCELERATION TIME	119	128	+9	122	127	+5	123	129	+6	122	128	+6	122	125	+3	121	130	+9
TIME TO 2ND BICEPS BURST	141	158	+17	142	139	-3	137	154	+17	133	148	+15	142	139	-3	139	152	+13
TIME TO 2ND TRICEPS BURST	62	74	+12	65	69	+4	63	72	+9	62	57	+5	65	55	-10	63	64	+1
LOAD 1																		
MOVEMENT TIME (90°)	138	152	+14	141	154	+13	140	151	+11	142	145	+3	140	140	0	138	151	+13
ACCELERATION TIME	127	135	+8	130	136	+6	129	138	+9	131	140	+9	131	138	+7	130	138	+8
TIME TO 2ND BICEPS BURST	139	162	+23	153	159	+6	150	160	+10	141	159	+18	145	151	+6	150	153	+3
TIME TO 2ND TRICEPS BURST	62	80	+18	67	77	+10	65	75	+10	64	63	-1	66	59	+7	64	67	+3
LOAD 2																		
MOVEMENT TIME (90°)	169	186	+17	170	185	+15	167	181	+14	170	173	+3	172	169	-3	169	180	+11
ACCELERATION TIME	147	150	+3	149	150	+1	149	156	+7	149	154	+5	149	155	+6	150	153	+3
TIME TO 2ND BICEPS BURST	175	188	+13	176	180	+4	177	187	+10	166	190	+24	173	171	-2	172	179	+7
TIME TO 2ND TRICEPS BURST	77	96	+19	82	94	+12	81	89	+8	80	80	0	81	72	-9	79	80	+1

TABLE 34 (con't.)

FATIGUE REGIMENS

WOMEN	FLEXION 5:5 Pre	FLEXION 5:5 Post	FLEXION 5:5 Δ**	FLEXION 5:10 Pre	FLEXION 5:10 Post	FLEXION 5:10 Δ**	FLEXION 5/5:0 Pre	FLEXION 5/5:0 Post	FLEXION 5/5:0 Δ**	EXTENSION 5:5 Pre	EXTENSION 5:5 Post	EXTENSION 5:5 Δ**	EXTENSION 5:10 Pre	EXTENSION 5:10 Post	EXTENSION 5:10 Δ**	EXTENSION 5/5:0 Pre	EXTENSION 5/5:0 Post	EXTENSION 5/5:0 Δ**
LOAD 0																		
MOVEMENT TIME (90°)	144	157	+13	141	156	+15	139	151	+12	144	149	+5	147	139	-8	138	155	+17
ACCELERATION TIME	135	139	+4	128	135	+7	128	138	+10	133	137	+4	133	129	-4	130	141	+11
TIME TO 2ND BICEPS BURST	169	180	+11	173	166	-7	178	194	+16	172	198	+26	179	194	+15	170	185	+15
TIME TO 2ND TRICEPS BURST	78	97	+19	76	85	+9	76	88	+12	76	74	-2	75	67	-8	72	87	+15
LOAD 1																		
MOVEMENT TIME (90°)	164	175	+11	158	169	+11	157	169	+12	162	167	+5	164	159	-5	157	171	+14
ACCELERATION TIME	145	151	+6	142	146	+4	142	146	+4	145	152	+7	145	148	+3	142	147	+17
TIME TO 2ND BICEPS BURST	199	198	-1	191	190	-1	192	203	+11	192	205	+13	196	217	+21	195	212	+17
TIME TO 2ND TRICEPS BURST	88	100	+12	82	90	+8	82	92	+10	85	79	-6	84	81	-3	79	93	+14
LOAD 2																		
MOVEMENT TIME (90°)	200	215	+15	195	-	+16	196	206	+10	197	203	+6	201	193	-8	197	208	+11
ACCELERATION TIME	163	162	-1	165	157	-8	169	171	+2	164	169	+5	166	168	+2	169	171	+2
TIME TO 2ND BICEPS BURST	241	237	4	234	263	+29	242	238	-4	227	257	+30	234	252	+18	251	241	-10
TIME TO 2ND TRICEPS BURST	112	128	+16	105	122	+17	109	118	+9	105	98	-7	105	98	-7	106	117	+11

* All measures are expressed in milliseconds.
**Δ = Differences

TABLE 35

VARIANCE ANALYSIS FOR MOVEMENT TIME FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	96142.99	1.88
Blocks w/groups (B:G)	2	51033.68	9.67**
Subjects w/blocks (S:BG)	20	5275.94	5.22
Days (D)	5	907.43	1.05
Regimens (R)	5	5167.10	7.51
Loads (L)	2	179879.34	529.29**
Load Order (O)	2	464.64	1.63
GD	5	503.54	.58
GR	5	819.82	1.19
GL	2	422.92	1.24
GO	2	1125.69	3.94
BD:G	10	863.18	.85
BR:G	10	688.00	.68
BL:G	4	339.85	.34
BO:G	4	285.90	.28
Error	352	1011.15	

**$p < .01$
* $p < .05$

Table 36. The pre and post fatigue means for movement time to maximal displacement and movement time for the first ninety degrees of forearm flexion are graphically illustrated in Figures 30 and 31, respectively. The imposed fatigue regimens did not elicit a significant difference between groups. However, when the first ninety degrees of forearm flexion were analyzed (Table 36) significant group differences were revealed. Figure 31 illustrates the remarkable similarity in the patterns of response, under each load condition, by both genders. Agonist fatigue regimens produced increased movement times, the magnitude of the increase was directly related to the intensity of the regimen. The regimens which sought to induce concurrent agonist and antagonist fatigue, designated as 5/5:0, resulted in increased movement times, for both groups, under all load conditions. Antagonist 5:10 fatigue produced decrease movement times, particularly for the women under load conditions 1 and 2. These results are in general agreement with the observations of Lagasse (54) and Wolcott (103). Lagasse (54) induced isometric antagonist fatigue and observed a significant increase in the expressed speed of forearm flexion (class B), whereas, isometric agonist fatigue produced non significant alterations. Wolcott (103) induced high and low intensity isotonic fatigue in agonist musculature with substantial increases in movement time (class A) under resisted and unresisted conditions. Isotonically induced antagonist

TABLE 36

VARIANCE ANALYSIS FOR MOVEMENT TIME FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	139191.17	92.41*
Blocks w/groups (B:G)	2	1506.26	.20
Subjects w/blocks (S:BG)	20	7416.44	56.30**
Days (D)	5	1340.12	2.57
Regimens (R)	5	8428.65	14.53**
Loads (L)	2	274095.18	3068.52**
Load Order (O)	2	42.69	.08
Trials (T)	2	854.10	19.01**
GD	5	891.11	1.71
GR	5	228.25	.39
GL	2	3284.49	36.77**
GO	2	111.63	.20
GT	2	13.03	.29
BD:G	10	521.47	3.96**
BR:G	10	580.21	4.40**
BL:G	4	89.32	.68
BO:G	4	557.82	4.23
BT:G	4	44.93	.34
Error	1208	131.72	

* $p < .05$
**$p < .01$

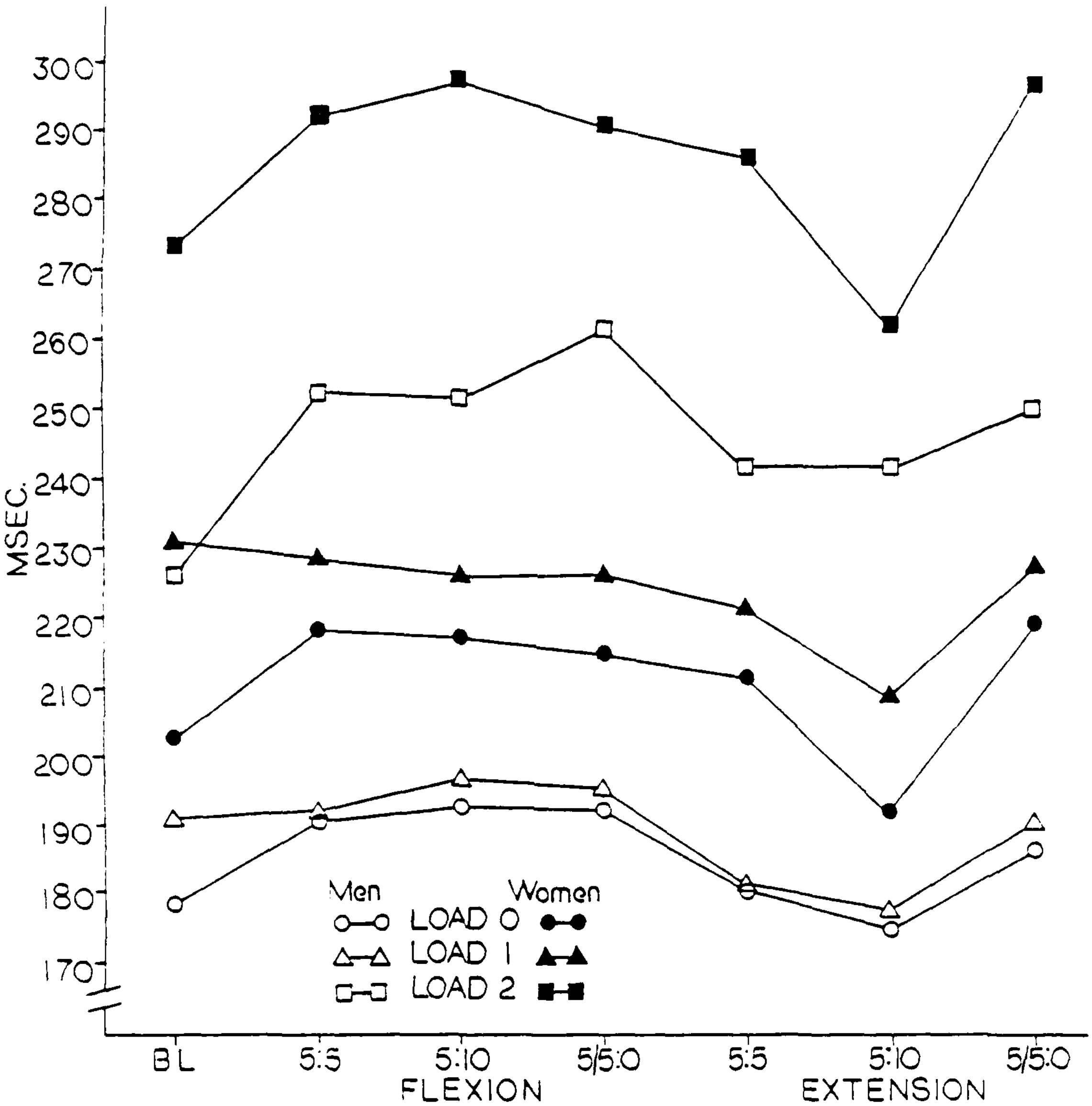

Fig. 30. Movement Time Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

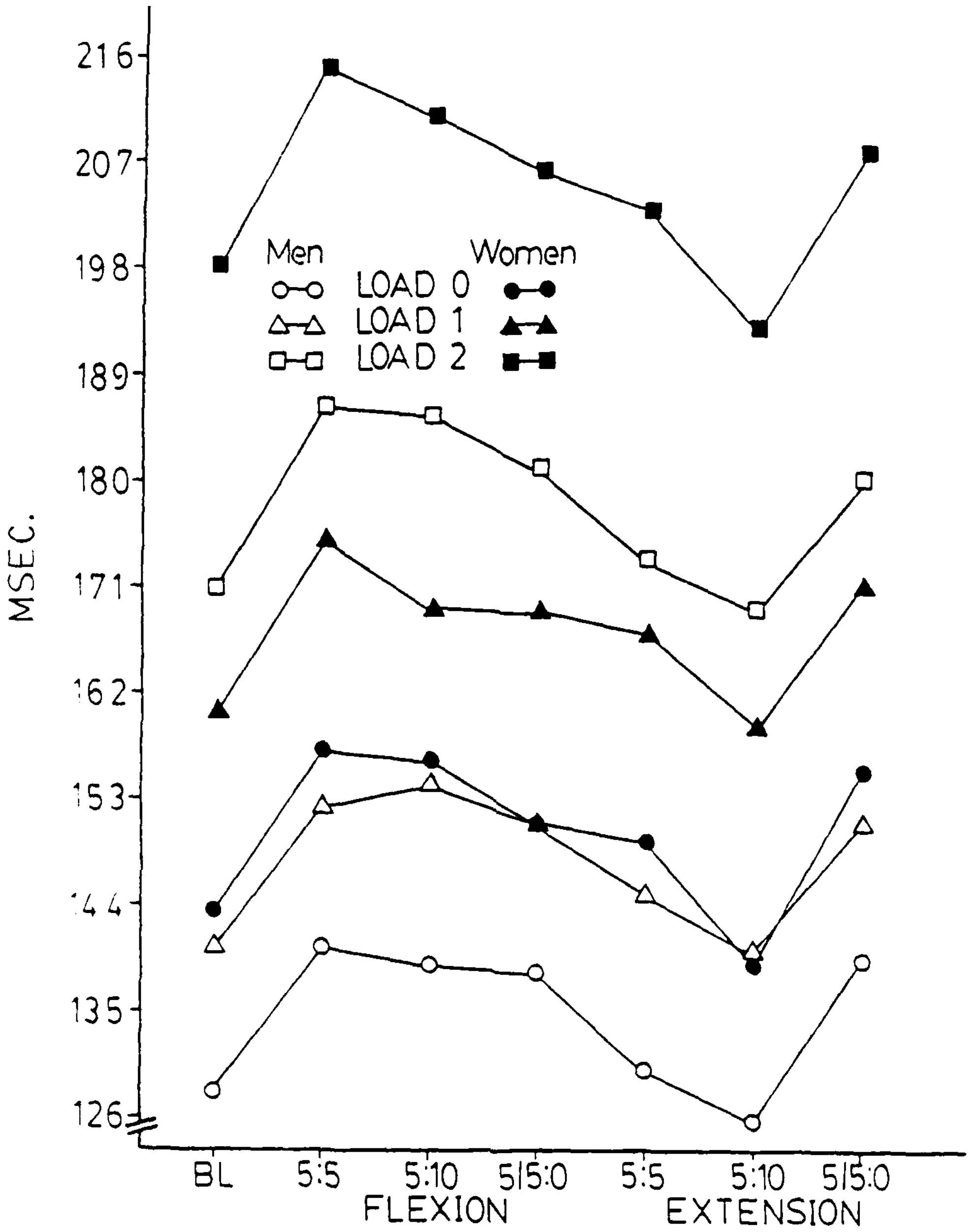

Fig. 31. Movement Time Means During the First Ninety Degrees of Forearm Flexion for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

fatigue did not significantly alter movement time, under any load condition.

Acceleration time. The variance analysis for acceleration time to maximal displacement is presented in Table 37; the analysis for acceleration time during the first ninety degrees of forearm flexion is presented in Table 38. Figures 32 and 33 depict the pre and post fatigue means presented in Tables 31, 32, 33, and 34. Significant gender differences were not observed. However, significant regimen and load effects were induced during the first ninety degrees of forearm flexion. Inspection of Figure 33 revealed a pattern of increased acceleration time, under all load conditions for the women. The men manifested less uniformity, although, a general pattern of increased acceleration time was observed.

Acceleration time to maximal displacement (Figure 32) decreased following antagonist fatigue regimens, especially the 5:10 exercise. Agonist fatigue regimens elicited increased acceleration times for the women, under load conditions 1 and 2; and for the men, under load conditions 0 and 2.

Time to maximal acceleration. The variance analysis following the fatigue regimens for this criterion measure to maximal displacement is presented in Table 39. The patterns of the pre and post fatigue means are depicted in Figure 31. No statistically significant effects were observed.

TABLE 37

VARIANCE ANALYSIS FOR ACCELERATION TIME FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	30782.37	5.03
Blocks w/groups (B:G)	2	6120.42	2.69
Subjects w/blocks (S:BG)	20	2279.30	5.38**
Days (D)	5	524.47	1.22
Regimens (R)	5	2725.63	10.43**
Loads (L)	2	47303.69	48.64**
Load Order (O)	2	280.82	1.24
GD	5	489.67	1.14
GR	5	475.99	1.82
GL	2	154.21	.16
GO	2	398.99	1.77
BD:G	10	428.42	1.01
BR:G	10	261.39	.62
BL:G	4	972.58	2.30
BO:G	4	225.65	.53
Error	352	423.43	

**$p < .01$
* $p < .05$

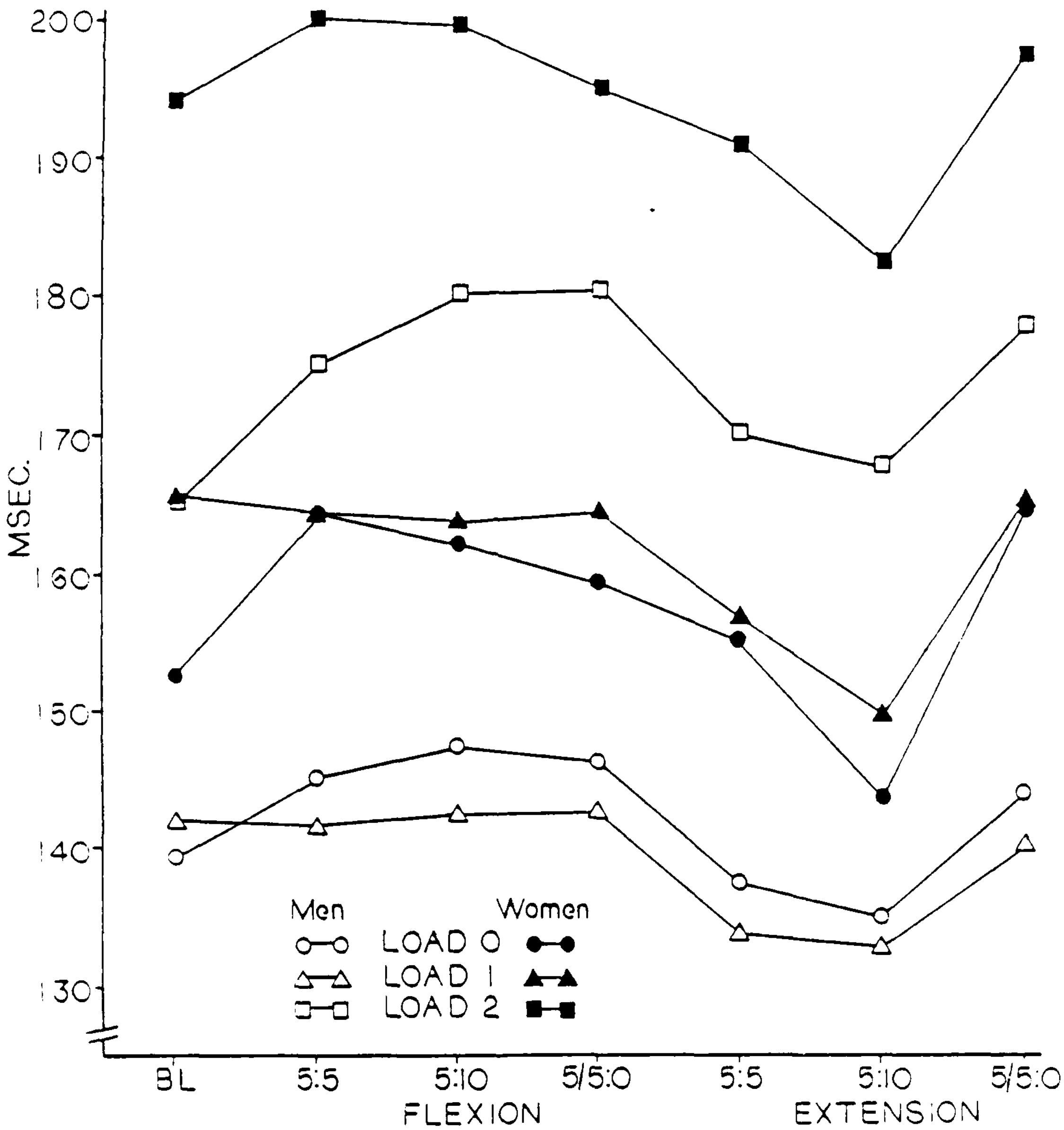

Fig. 32. Acceleration Time Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

TABLE 38

VARIANCE ANALYSIS FOR ACCELERATION TIME FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	38896.60	7.73
Blocks w/groups (B:G)	2	5029.38	.68
Subjects w/blocks (S:BG)	20	7363.73	40.83**
Days (D)	5	377.14	1.04
Regimens (R)	5	867.11	1.39
Loads (L)	2	83275.65	1874.16**
Load Order (O)	2	32.23	.18
Trials (T)	2	247.97	18.40**
GD	5	1681.75	4.62
GR	5	190.33	.31
GL	2	501.00	11.28*
GO	2	430.83	2.38
GT	2	6.21	.46
BD:G	10	363.81	2.02*
BR:G	10	621.88	3.45**
BL:G	4	44.43	.25
BO:G	4	181.38	1.01
BT:G	4	13.47	.07
Error	1208	180.35	

* $p < .05$
**$p < .01$

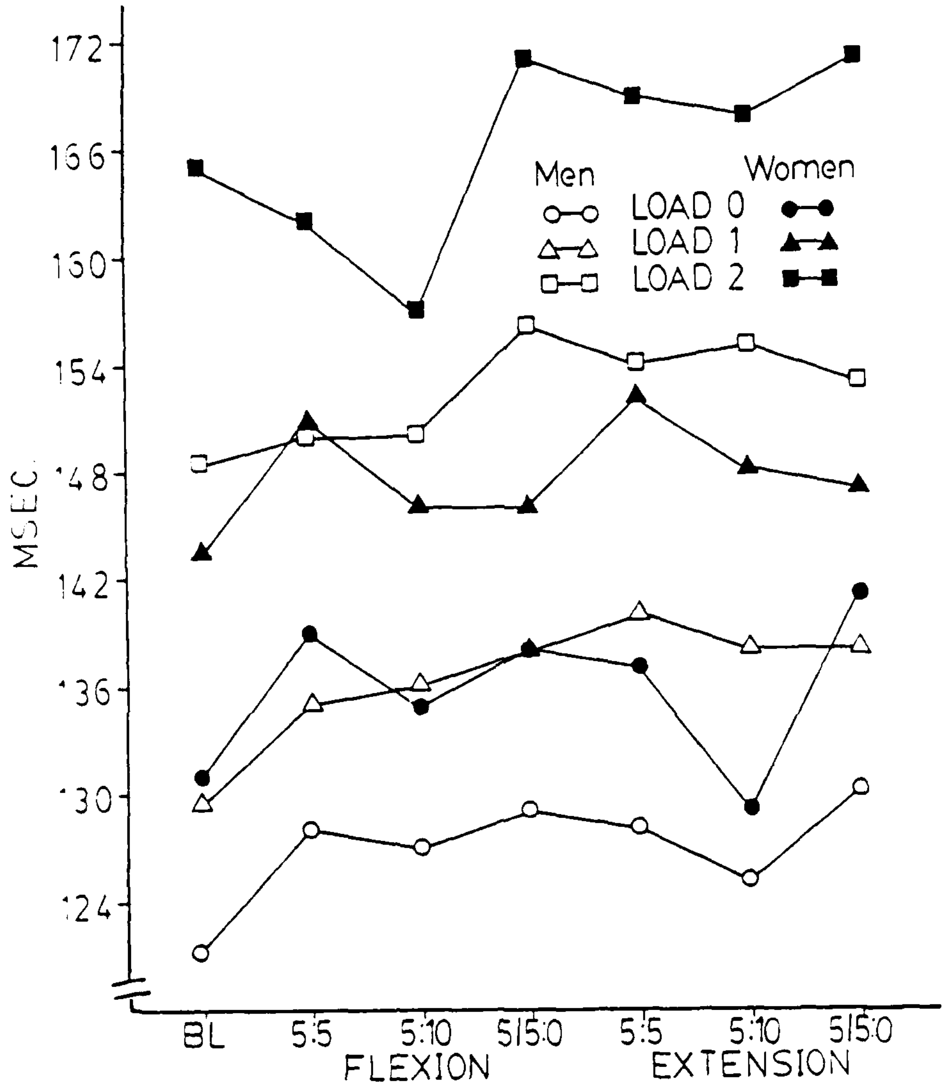

Fig. 33. Acceleration Time Means During the First Ninety Degrees of Forearm Flexion for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

TABLE 39

VARIANCE ANALYSIS FOR THE TIME TO MAXIMAL ACCELERATION FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups(G)	1	4711.74	2.88
Blocks w/groups(B:G)	2	1633.85	.91
Subjects w/groups(S:BG)	20	1791.46	.02
Days(D)	5	406.71	.99
Regimens(R)	5	430.66	2.02
Loads(L)	2	6504.01	3.63
Load Order(O)	2	289.54	1.82
GD	5	200.66	.49
GR	5	450.23	2.11
GL	2	399.88	.22
GO	2	356.08	2.24
BD:G	10	409.28	1.74
BR:G	10	213.07	.91
BL:G	4	1791.26	7.61**
BO:G	4	158.66	.67
Error	352	235.26	

**$p < .01$
* $p < .05$

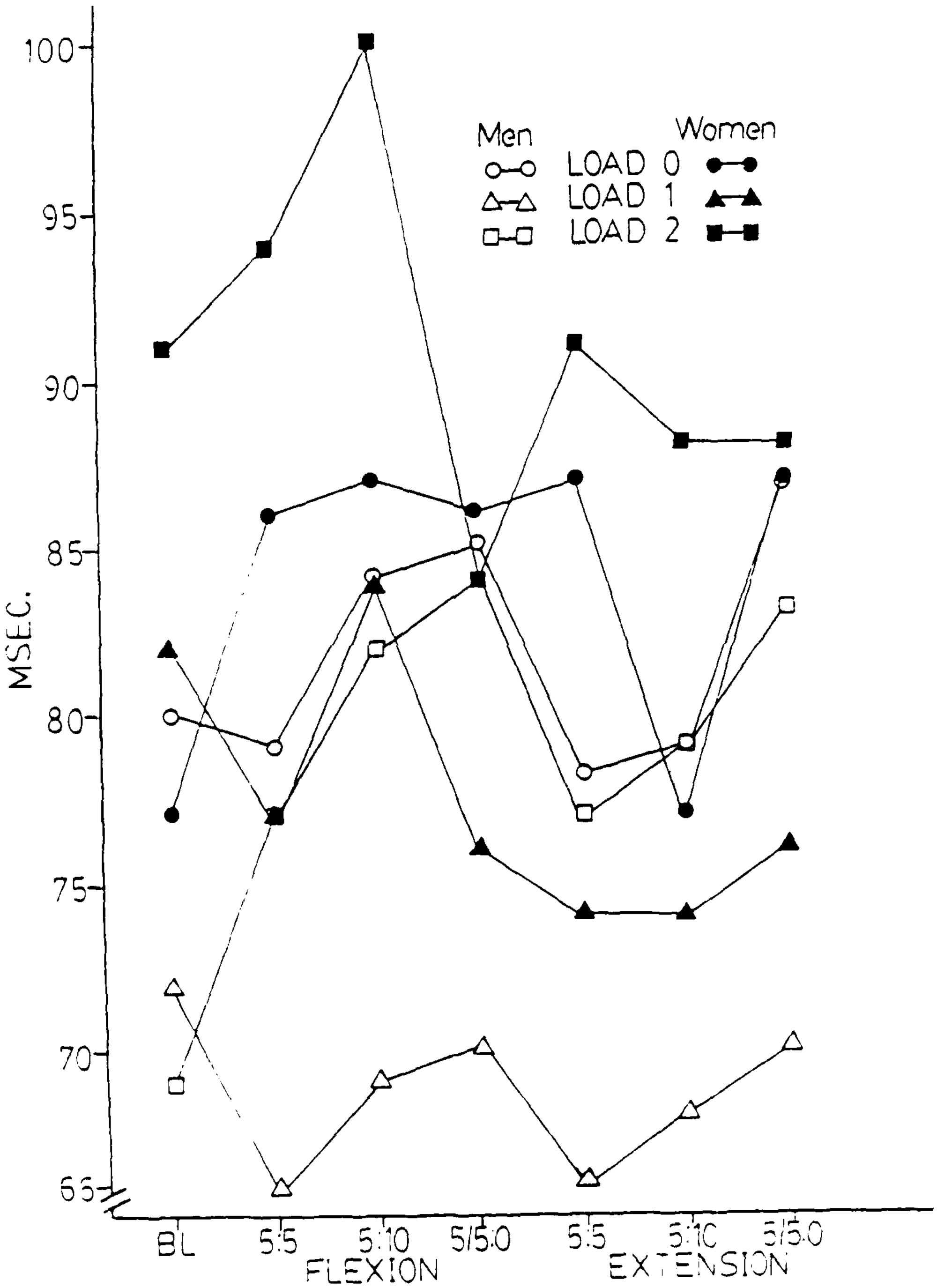

Fig. 34. Time to Maximal Acceleration Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

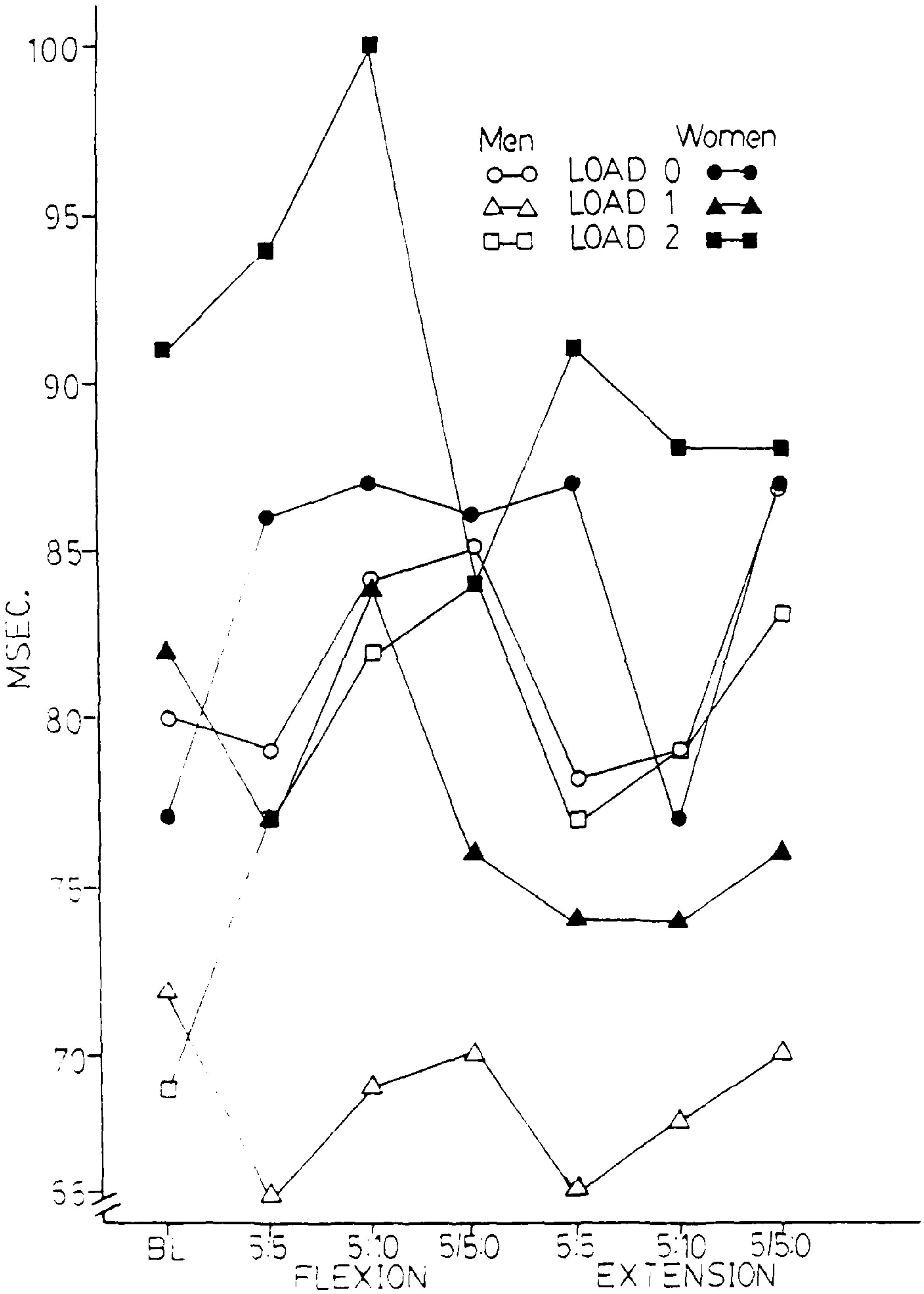

Fig. 34. Time to Maximal Acceleration Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

First biceps motor time. Table 40 presents the variance analysis for this criterion measure to maximal displacement. Figure 35 illustrates the significant gender and load condition differences. However, significant differences between agonist and antagonist fatigue regimens were not observed.

First biceps duration. The variance analysis for this criterion measure, to maximal displacement, is presented in Table 41, with a graphic representation of the pre and post fatigue means presented in Figure 36. Although, significant gender and load effects were revealed, the differences elicited by the fatigue regimens did not attain statistical significance.

Time to second biceps burst. The post fatigue analysis of variance for this criterion measure, during the first ninety degrees of forearm flexion, is presented in Table 42. The pre and post fatigue means, presented in Table 34, are graphically depicted in Figure 37. Significant gender and load condition effects were observed. The women, under all load conditions, experienced a delay in the onset of the second biceps burst, the most pronounced delays followed antagonist fatigue regimens. The patterns of response produced by the men also included delays in the time to the second biceps burst, except following the 5:10 antagonist fatigue regimen.

First triceps motor time. The post fatigue analysis for this criterion measure to maximal displacement is presented

TABLE 40

VARIANCE ANALYSIS FOR BICEPS MOTOR TIME FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	10617.68	41.02*
Blocks w/groups (B:G)	2	258.86	.35
Subjects w/blocks (S:B)	20	749.30	3.13
Days (D)	5	285.49	.63
Regimens (R)	5	340.22	1.40
Loads (L)	2	34117.09	1082.77**
Load Order (O)	2	120.73	4.19
GD	5	96.22	.21
GR	5	38.93	.16
GL	2	92.50	2.94
GO	2	62.92	2.18
BD:G	10	455.83	1.91
BR:G	10	243.80	1.02
BL:G	4	31.51	.13
BO:G	4	28.80	.12
Error	352	239.28	

**$p < .01$
* $p < .05$

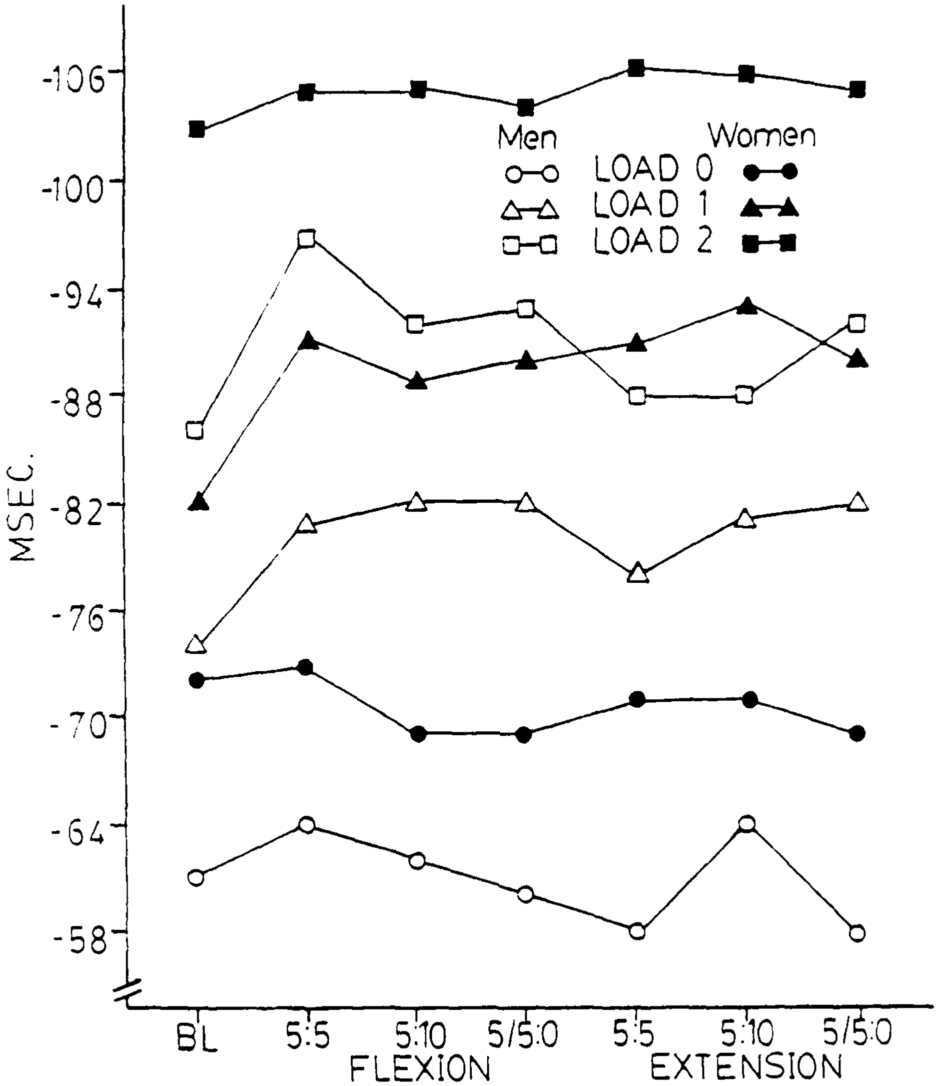

Fig. 35. First Biceps Motor Time Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

TABLE 41

VARIANCE ANALYSIS FOR BICEPS DURATION(1B) FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups(G)	1	55235.10	25.45*
Blocks w/groups(B:G)	2	2170.42	.50
Subjects w/blocks(S:BG)	20	4368.68	5.78**
Days(D)	5	1005.41	1.38
Regimens(R)	5	1188.22	1.36
Loads(L)	2	60807.56	192.00**
Load Order(O)	2	684.45	2.51
GD	5	413.43	.57
GR	5	583.84	.67
GL	2	378.46	1.19
GO	2	684.31	2.51
BD:G	10	730.05	.97
BR:G	10	873.57	1.16
BL:G	4	316.71	.42
BO:G	4	272.16	.36
Error	352	756.26	

**p < .01
* p < .05

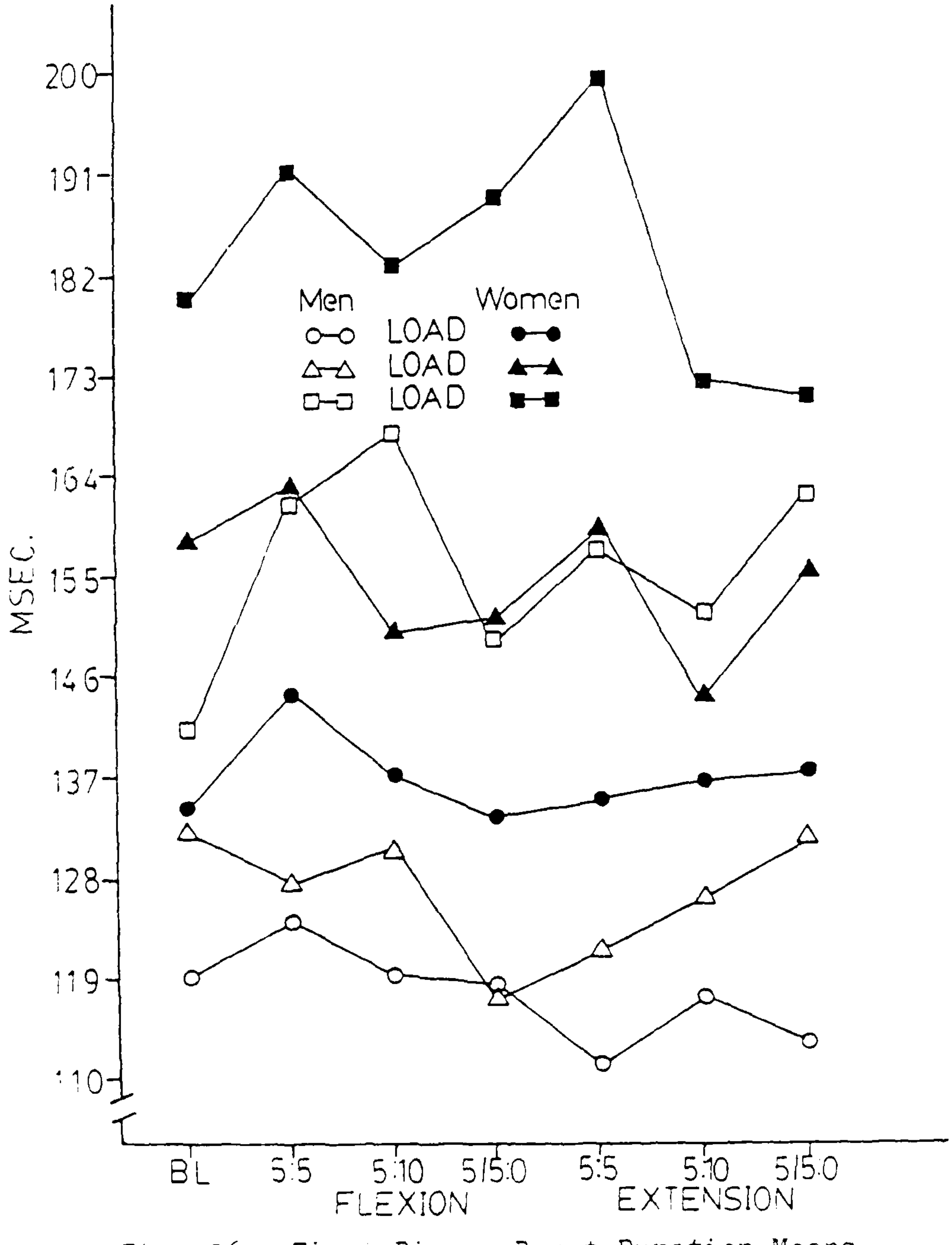

Fig. 36. First Biceps Burst Duration Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

TABLE 42

VARIANCE ANALYSIS FOR THE TIME TO SECOND BICEPS BURST FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	812301.63	32.74*
Blocks w/groups (B:G)	2	24809.48	.37
Subjects w/blocks (S:BG)	20	67054.33	73.14**
Days (D)	5	8463.83	1.65
Regimens (R)	5	2266.47	.65
Loads (L)	2	265227.27	64.37**
Load Order (O)	2	3003.41	13.50*
Trials (T)	2	355.60	1.16
GD	5	5351.42	1.04
GR	5	6061.57	1.73
GL	2	21785.13	5.29
GO	2	50.60	.23
GT	2	1220.23	3.99
BD:G	10	5132.56	5.60**
BR:G	10	3512.69	3.83**
BL:G	4	4120.31	4.49**
BO:G	4	222.55	.24
BT:G	4	305.92	.33
Error	1208	916.82	

* $p < .05$
**$p < .01$

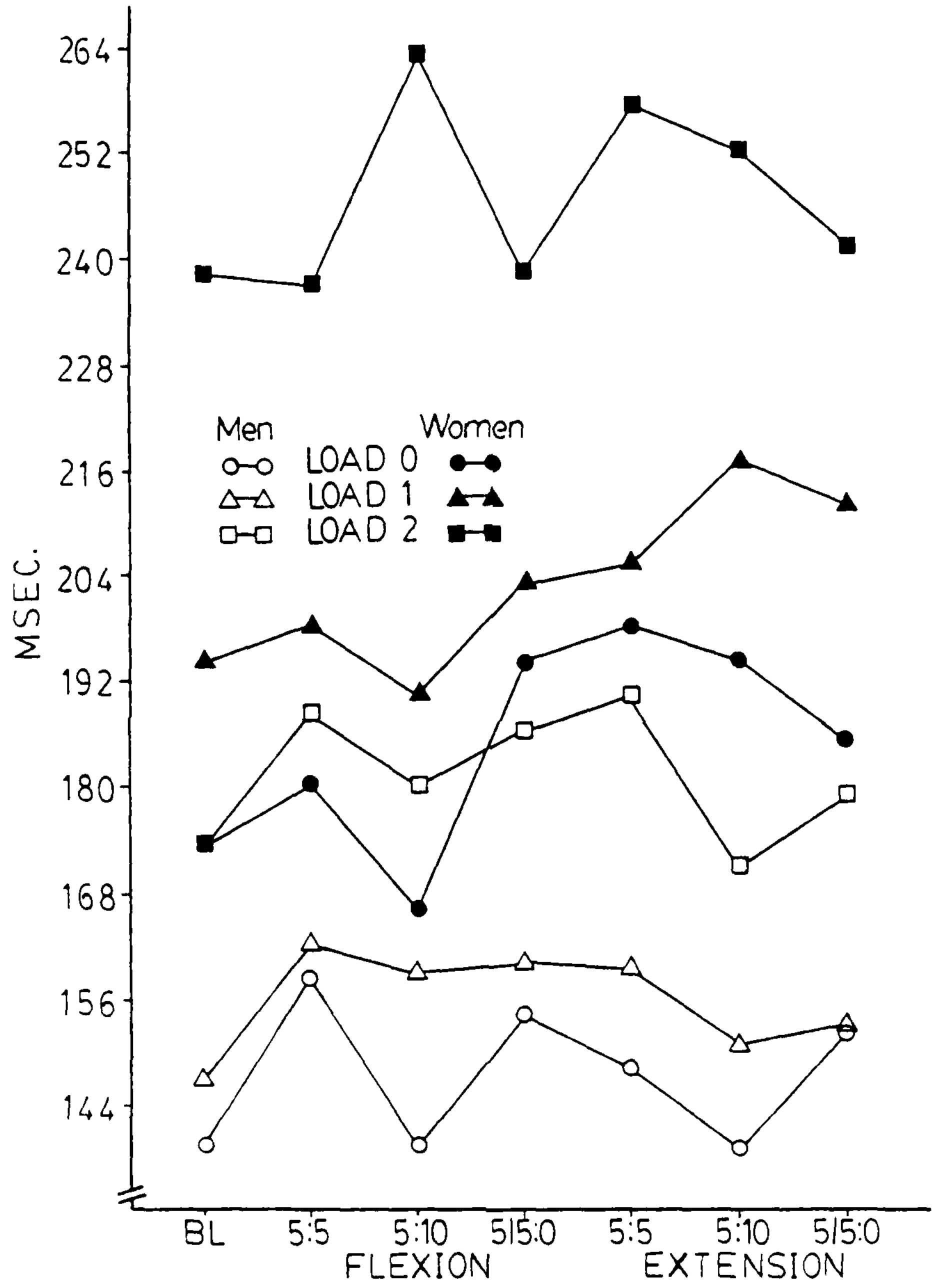

Fig. 37. Time to Second Biceps Burst Means During the First Ninety Degrees of Forearm Flexion for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

in Table 43. Although, Figure 38 illustrates distinct increases in first triceps motor time following 5:5 and 5:10 antagonist fatigue regimens, for the women, the differences were not significant.

Second triceps motor time. Table 44 presents the variance analysis for this criterion measure to maximal displacement. The imposed fatigue regimens did not elicit gender differences nor were the changes observed in second triceps motor time (Figure 39), following the fatigue regimens, significant.

Second triceps duration. The post fatigue variance analysis for this criterion measure to maximal displacement, is presented in Table 45. Figure 40 illustrates the significant *gender, regimen,* and load condition effects. Except, for the women under load condition 0, antagonist fatigue regimens, 5:5 and 5:10, lengthened the duration of the second burst from the triceps brachii. The response to 5:5 agonist fatigue was diametrically opposite for the men and women, under all load conditions.

Time to second triceps burst. The analysis of variance for this criterion measure, during the first ninety degrees of forearm flexion, is presented in Table 41. The significant gender, regimen, and load *conditions effects are graphically* presented in Figure 41. Dramatic delays in the time to the second triceps burst occurred in reponse to agonist fatigue regimens, the women incurred the most pronounced delays. The reponse to antagonist fatigue regimens was an earlier

TABLE 43

VARIANCE ANALYSIS FOR TRICEPS MOTOR TIME FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	32656.68	2.30
Blocks w/groups (B:G)	2	14175.84	1.69
Subjects w/blocks (S:BG)	20	8389.81	6.71
Days (D)	5	977.63	.79
Regimens (R)	5	1782.93	1.49
Loads (L)	2	21433.92	1.56
Load Order (O)	2	258.98	.43
GD	5	699.87	.57
GR	5	1112.31	.93
GL	2	9319.75	.68
GO	2	735.39	1.22
BD:G	10	1237.46	.99
BR:G	10	1200.02	.96
BL:G	4	13753.41	11.00**
BO:G	4	605.17	.48
Error	352	1250.82	

**$p < .01$

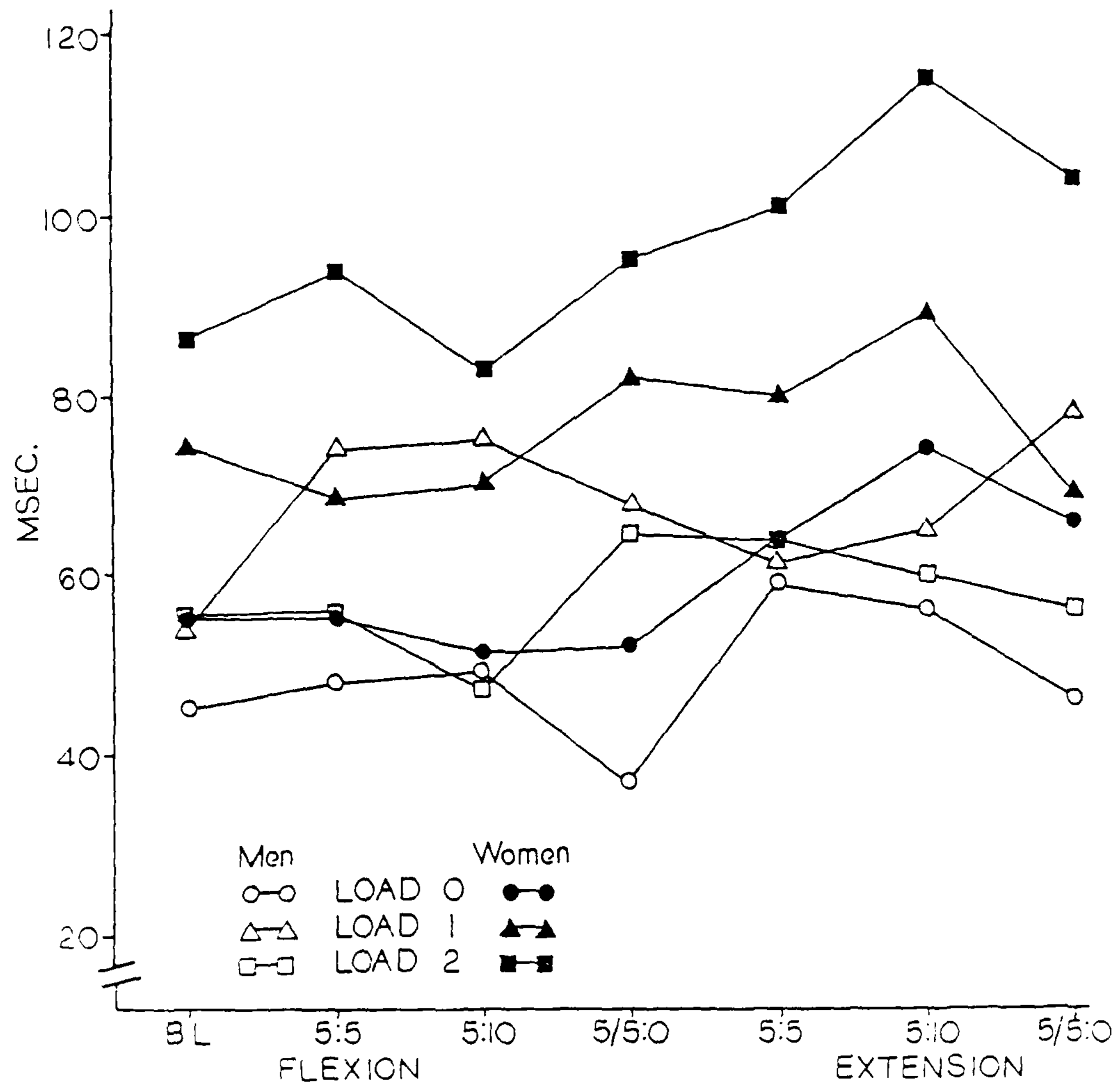

Fig. 38. First Triceps Burst Motor Time Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

TABLE 44

VARIANCE ANALYSIS FOR TRICEPS MOTOR TIME (SECOND BURST) FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	22650.92	8.09
Blocks w/groups (B:G)	2	2798.93	1.44
Subjects w/blocks (S:BG)	20	1939.14	3.74**
Days (D)	5	461.45	1.06
Regimens (R)	5	526.77	.85
Loads (L)	2	98437.99	43.29**
Load Order (O)	2	490.72	5.91
GD	5	469.71	1.07
GR	5	240.23	.39
GL	2	342.96	.15
GO	2	1257.82	15.14*
BD:G	10	437.13	.84
BR:G	10	622.96	1.20
BL:G	4	2273.91	4.38**
BO:G	4	83.08	.16
Error	352	518.73	

**$p < .01$
* $p < .05$

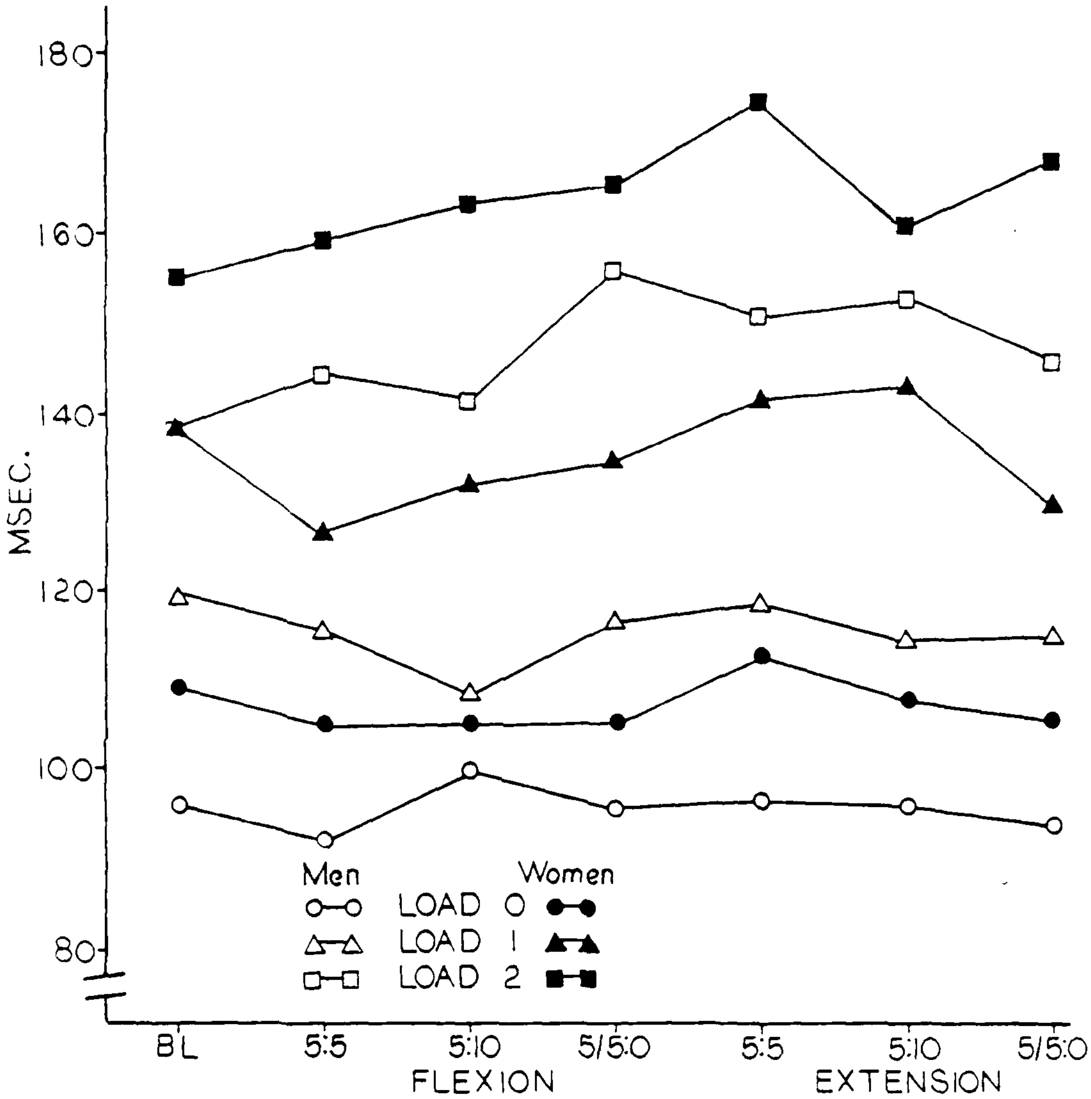

Fig. 39. Second Triceps Burst Motor Time Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

TABLE 45

VARIANCE ANALYSIS FOR TRICEPS DURATION(2B) FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups(G)	1	38186.37	10127.18**
Blocks w/groups(B:G)	2	3.77	.00
Subjects w/blocks(S:BG)	20	5431.85	8.49
Days(D)	5	349.11	1.01
Regimens(R)	5	2670.48	4.72*
Loads(L)	2	37858.30	41.60**
Load Order(O)	2	484.72	2.56
GD	5	861.89	2.49
GR	5	307.42	.54
GL	2	3590.11	3.95
GO	2	149.53	.79
BD:G	10	346.69	.54
BR:G	10	566.31	.88
BL:G	4	909.84	1.42
BO:G	4	189.51	.30
Error	352	640.11	

**p < .01
* p < .05

TABLE 46

VARIANCE ANALYSIS FOR THE TIME TO SECOND TRICEPS BURST FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	152490.25	30.49*
Blocks w/groups (B:G)	2	5001.88	.45
Subjects w/blocks (S:BG)	20	11152.53	47.01**
Days (D)	5	1370.95	.89
Regimens (R)	5	17557.00	27.60**
Loads (L)	2	76247.65	277.81**
Load Order (O)	2	364.63	1.15
Trials (T)	2	2012.60	5.49
GD	5	1373.32	.89
GR	5	950.64	1.49
GL	2	3308.18	12.05*
GO	2	91.08	.29
GT	2	129.49	.35
BD:G	10	1548.94	6.53**
BR:G	10	636.23	2.68**
BL:G	4	274.46	1.16
BO:G	4	318.43	1.34
BT:G	4	366.64	1.55
Error	1208	237.27	

* $p < .05$
** $p < .01$

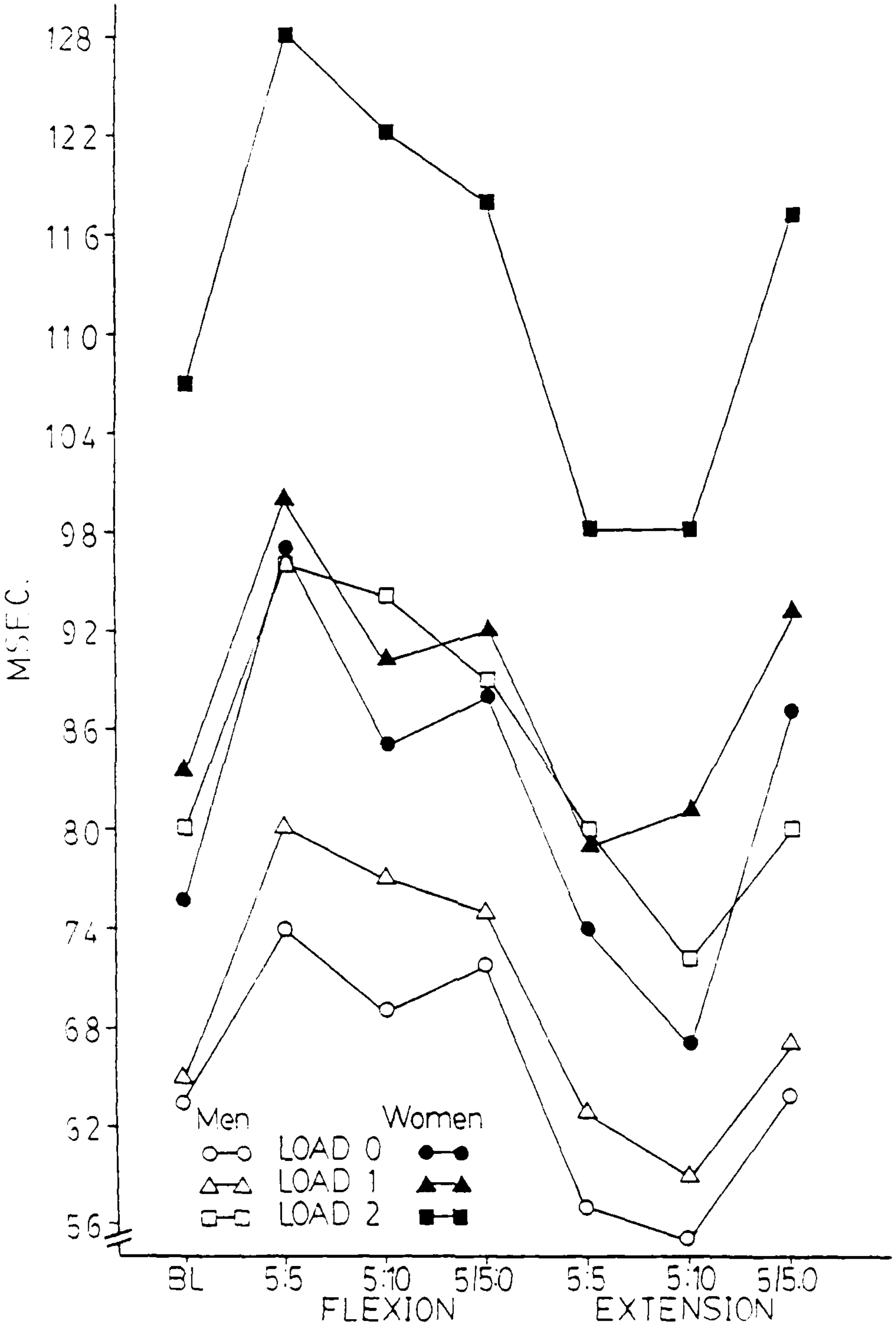

Fig. 41. Time to Second Triceps Burst Means During the First Ninety Degrees of Forearm Flexion for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

onset of the second triceps burst. Under all load conditions, the responses to the 5/5:0 antagonist fatigue regimen resembled the responses to agonist fatigue regimens, that is, delayed onset of the second triceps burst. The inducement of a fatigue state necessitated compensation in the onset and the duration of the second triceps burst, while the second triceps motor time was minimally effected.

First biceps burst to second triceps burst latency. Table 47 presents the post fatigue analysis of variance for this criterion measure to maximal displacement. Gender differences were not observed, however, significant regimen and load condition effects were revealed. Figure 42 illustrates the increased latencies in response to agonist fatigue regimens, including both 5/5:0 fatigue regimens. Antagonist fatigue regimens, 5:5 and 5:10, were followed by shortened latencies, for both groups under all load conditions.

Second triceps burst to maximal acceleration latency. The post fatigue analysis for this criterion measure, to maximal displacement, is presented in Table 48. Load condition and regimen effects attained statistical significance. Figure 48 graphically represents the shortened latencies which followed agonist fatigue regimens, 5:5 and 5:10, fatigue regimens; and the lengthened latencies which followed antagonist, 5:5 and 5:10, fatigue regimens. Except for the men under load condition 2, both 5/5:0 fatigue regimens were followed by lengthened latencies.

TABLE 47

VARIANCE ANALYSIS FOR FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	72567.97	13.16
Blocks w/groups (B:G)	2	5512.24	1.27
Subjects w/blocks (S:BG)	20	4348.78	4.77**
Days (D)	5	1486.84	1.46
Regimens (R)	5	8740.33	25.93**
Loads (L)	2	84531.34	35.77**
Load Order (O)	2	347.67	2.31
GD	5	145.78	.14
GR	5	329.58	.98
GL	2	785.34	.33
GO	2	1139.87	7.56*
BD:G	10	1017.46	1.12
BR:G	10	337.06	.37
BL:G	4	2363.29	2.59*
BO:G	4	150.70	.17
Error	352	911.47	

**$p < .01$
* $p < .05$

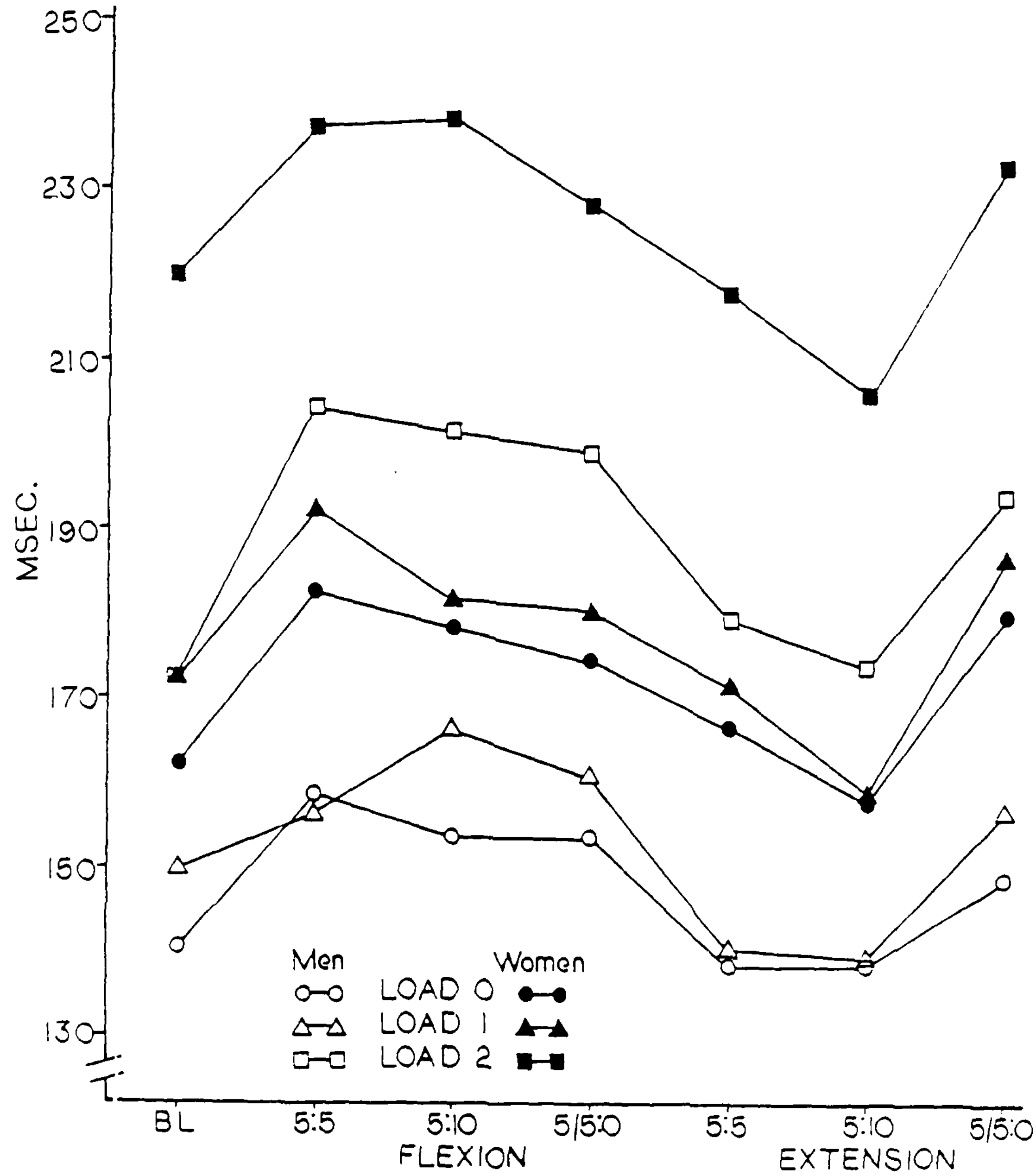

Fig. 42. First Biceps Burst to Second Triceps Burst Latency Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

TABLE 48

VARIANCE ANALYSIS FOR THE SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	7344.23	9.99
Blocks w/groups (B:G)	2	734.92	.38
Subjects w/blocks (S:BG)	20	1929.17	5.55**
Days (D)	5	666.03	1.00
Regimens (R)	5	4802.12	34.83**
Loads (L)	2	10132.00	14.67*
Load Order (O)	2	128.01	1.49
GD	5	368.71	.55
GR	5	454.39	3.30
GL	2	307.73	.45
GO	2	227.87	2.66
BD:G	10	667.23	1.92
BR:G	10	137.86	.40
BL:G	4	690.59	1.99
BO:G	4	85.75	.25
Error	352	347.34	

**$p < .01$
* $p < .05$

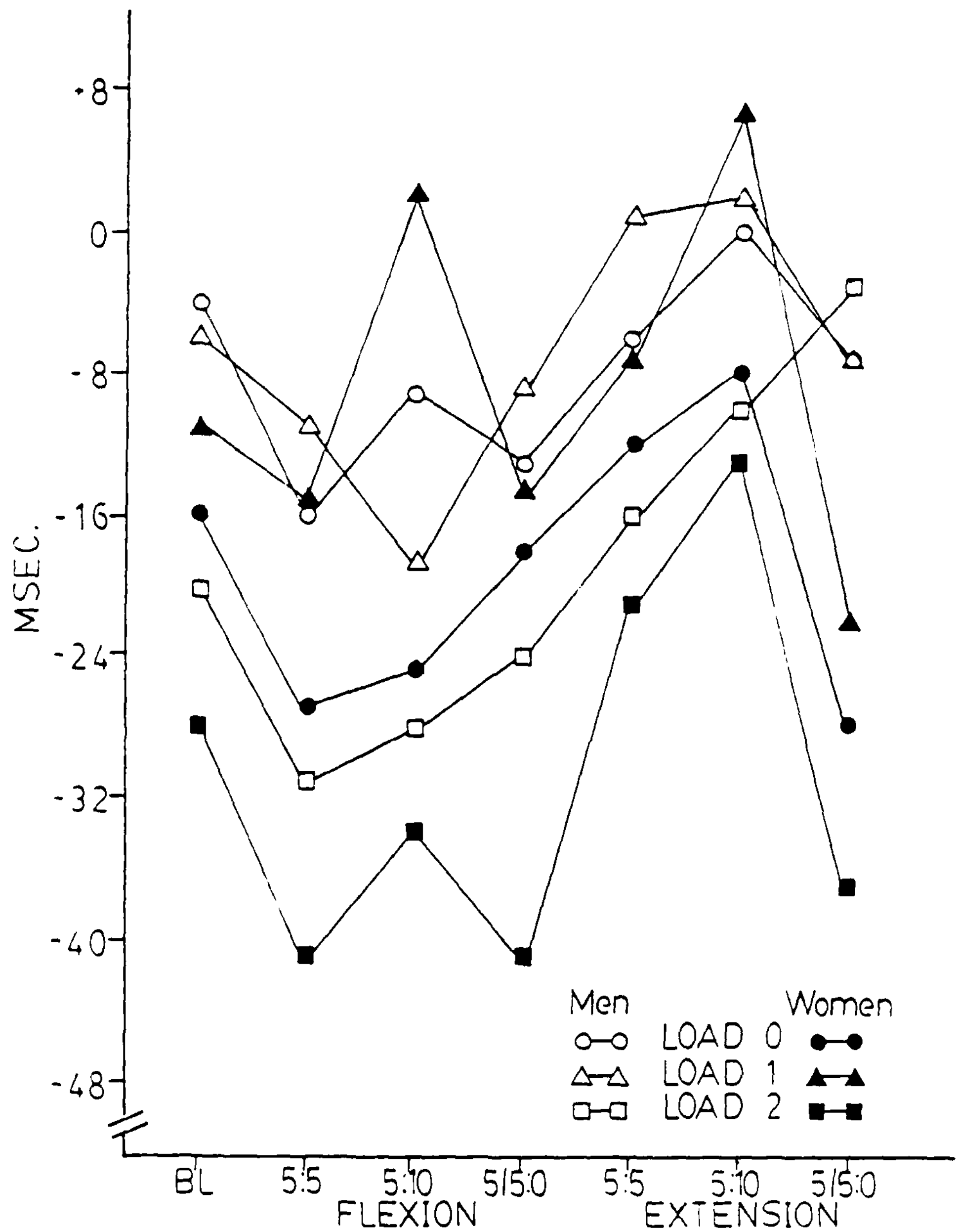

Fig. 43. Second Triceps Burst to Maximal Acceleration Latency Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

Second triceps burst to zero acceleration latency. Table 49 presents the post fatigue variance analysis for this criterion measure to maximal displacement. Load condition and regimen effects attained significance. Figure 44 depicts the shortened latencies which followed agonist, 5:5 and 5:10, fatigue regimens. Antagonist fatigue regimens, particularly under load conditions 1 and 2, were followed by lengthened latencies.

Slope of the first biceps burst EMG. The variance analysis following fatigue regimens for this criterion measure, to maximal displacement, is presented in Table 50. Figure 45 dramatically presents the pronounced gender differences. However, load condition and regimen effects did not attain statistical significance.

Slope of the second triceps burst EMG. The post fatigue analysis of variance for this criterion measure, to maximal displacement, is presented in Table 51. Significant group, load condition, and regimen effects were observed. Figure 46 graphically illustrates the effect of a highly significant groups by regimens interaction. The slope of the second triceps burst EMG was pronouncely effected by antagonist fatigue regimens, in the women under all load conditions. The imposed fatigue regimens did not elicit compensation by the slope of the second triceps burst EMG, in the men.

TABLE 49

VARIANCE ANALYSIS FOR SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	328.06	.58
Blocks w/groups (B:G)	2	567.33	.59
Subjects w/blocks (S:BG)	20	964.93	3.86**
Days (D)	5	439.95	3.29
Regimens (R)	5	1241.38	3.87*
Loads (L)	2	14104.65	25.70**
Load Order (O)	2	263.05	.48
GD	5	421.73	3.15
GR	5	192.85	.60
GL	2	741.26	1.35
GO	2	489.68	8.63*
BD:G	10	133.69	.54
BR:G	10	320.94	1.29
BL:G	4	548.73	2.20
BO:G	4	56.72	.23
Error	352	249.69	

**$p < .01$
* $p < .05$

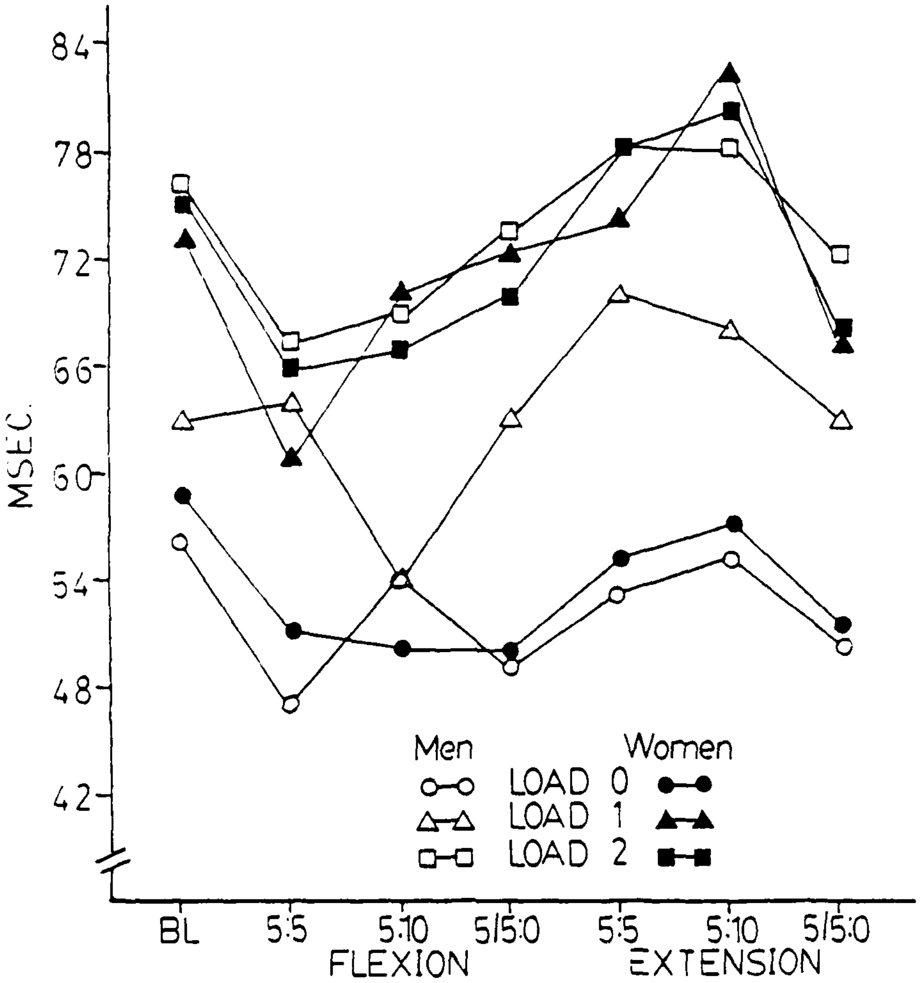

Fig. 44. Second Triceps Burst to Zero Acceleration Latency Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

TABLE 50

VARIANCE ANALYSIS FOR THE SLOPE OF THE FIRST BICEPS BURST FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	972.51	70.36*
Blocks w/groups (B:G)	2	13.82	.89
Subjects w/blocks (S:BG)	20	15.49	5.88**
Days (D)	5	.73	.35
Regimens (R)	5	3.62	1.10
Loads (L)	2	6.86	.85
Load Order (O)	2	.69	1.44
GD	5	1.42	.68
GR	5	.87	.27
GL	2	.16	.02
GO	2	1.22	2.56
BD:G	10	2.09	.79
BR:G	10	3.30	1.25
BL:G	4	8.02	3.05*
BO:G	4	.48	.18
Error	352	2.63	

**$p < .01$

* $p < .05$

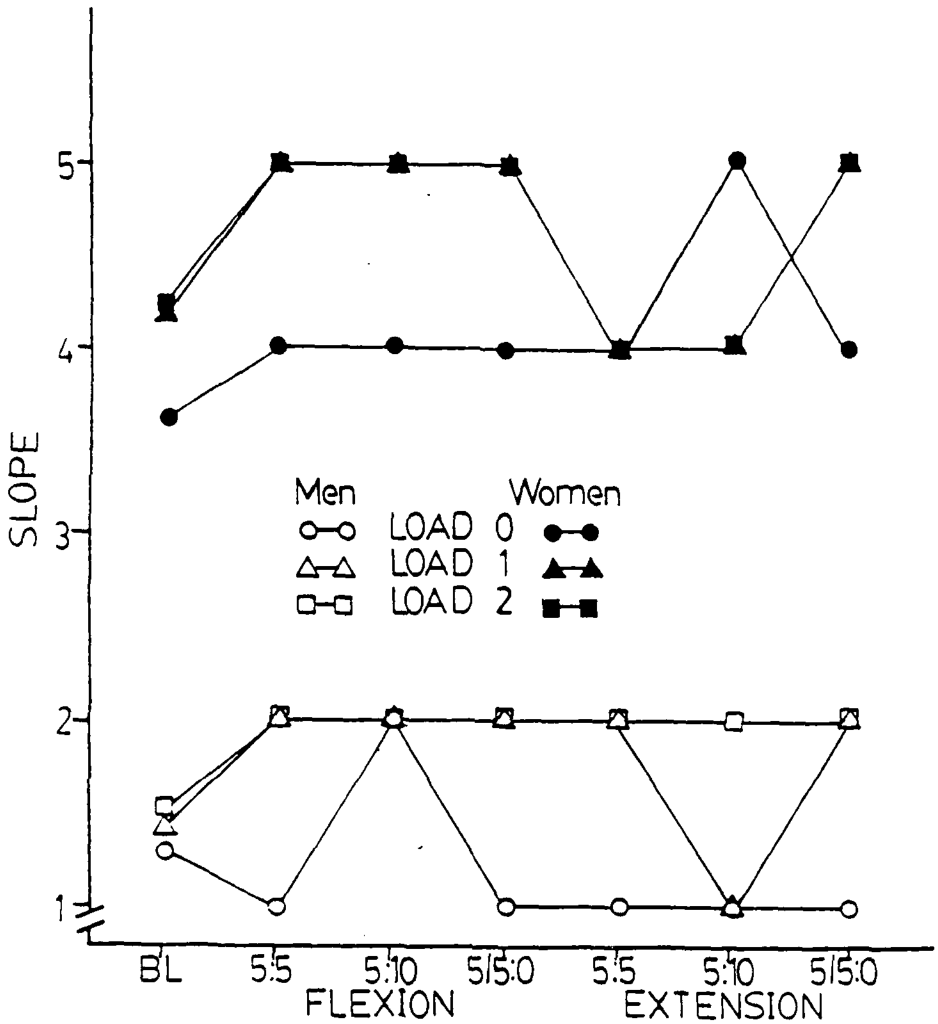

Fig. 45. Slope of the First Biceps Burst EMG Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

TABLE 51

VARIANCE ANALYSIS FOR THE SLOPE OF THE SECOND TRICEPS BURST FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	7559.45	37.98*
Blocks w/groups (B:G)	2	199.28	.40
Subjects w/groups (S:BG)	20	504.26	9.22**
Days (D)	5	62.54	3.28
Regimens	5	168.07	9.31**
Loads (L)	2	1155.53	12.58*
Load Order (O)	2	86.72	2.39
GD	5	52.66	2.77
GR	5	184.02	10.19**
GL	2	298.70	3.25
GO	2	55.90	1.54
BD:G	10	19.04	.35
BR:G	10	18.06	.33
BL:G	4	91.87	1.68
BO:G	4	36.24	.66
Error	352	54.67	

**$p < .01$
* $p < .05$

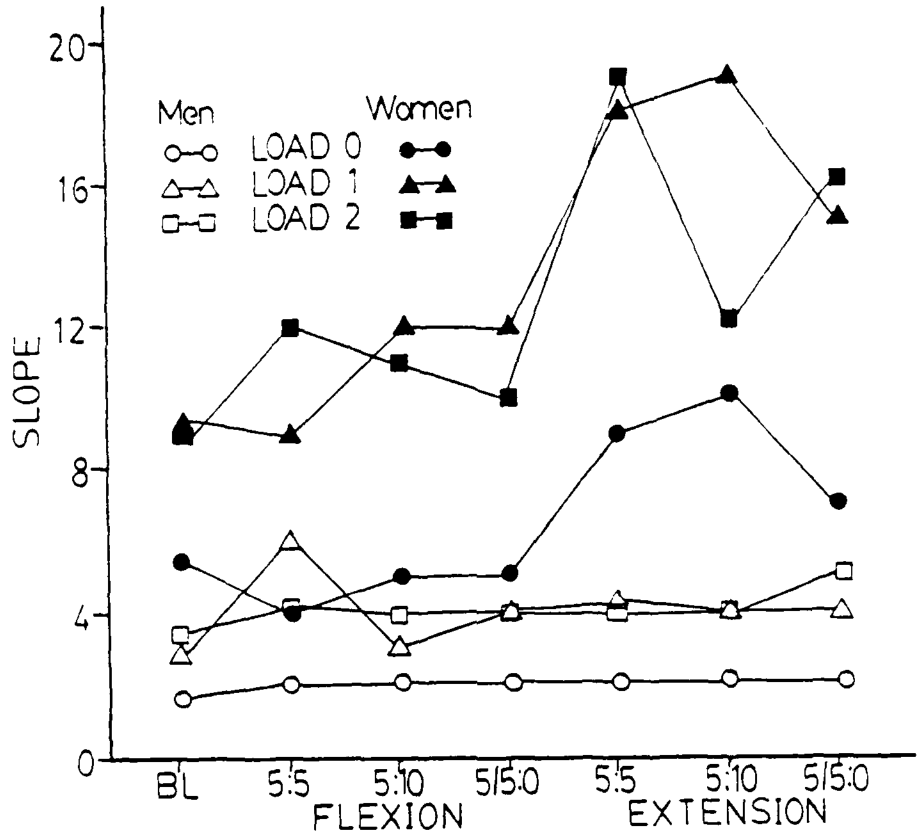

Fig. 46. Slope of the Second Triceps Burst EMG Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

Selected criterion measures. The following criterion measures: the ratio between the first biceps burst EMG and the second triceps burst EMG, the ratio between total biceps EMG and total triceps EMG, first biceps burst to first triceps burst latency, biceps silent period, accuracy, and maximal displacement did not manifest significant gender, load condition, or regimen effects following the imposition of isometric agonist and antagonist fatigue regimens. Complete post fatigue analysis of variance tables are contained in Appendix E. Graphic representations of the pre and post fatigue means, presented in Tables 31, 32, 33, and 34, are contained in Appendix F.

Discussion of the Results

Power

The post mortem analysis (presented in Appendix A) yielded a statistical power in excess of 90 percent. This result represented an increase from the level of power established during the computation of the sample size estimate. The key factors responsible for the increased power were the lower standard deviations in comparison to the standard deviations, gleaned from Wolcott's (103) investigation, that were used in the sample size estimation. The major consequence of an increased power value is a reduction in the probability of committing a Type II error, that is, retaining a null hypothesis that is false.

These results would allow for a reduction in the number of subjects required at the pre-experimental power of 80. However, other criterion measures did not exhibit high intraclass reliability coefficients and low standard deviations, therefore, any changes in the number of subjects should be towards increasing the sample size.

Practice effects

Contrasting practice day 1 with practice day 4, the men decreased movement time to maximal displacement by 13.5 msec., 14.3 msec., and 8.1 msec. under load conditions 0, 1, and 2, respectively. The women decreased movement time to maximal displacement by 33.1 msec., 16.3 msec., and 15.9 msec. under load conditions 0, 1, and 2, respectively. In a similar comparison, during the first ninety degrees of forearm flexion, the men decreased movement time by 4.0 msec., 9.4 msec., and 0.4 msec. under load conditions 0, 1, and 2, respectively. The women decreased movement time by 19.2 msec., 14.6 msec., and 12.3 msec. under load conditions 0, 1, and 2, respectively. Clearly the women experienced more pronounced practice effects, enabling them to narrow the difference between the genders, particularly during the first ninety degrees of flexion. The women were not as successful in narrowing the difference between the genders in movement time to maximal displacement due to accuracy deficiencies. They were less accurate and, therefore, flexed further past the ninety degree target resulting in increased movement times.

Gender influences were also revealed in acceleration time to maximal displacement and in acceleration time during the first ninety degrees of forearm flexion. In both cases the women maintained the longer acceleration times, under all load conditions. The women exhibited a significantly longer time to the second burst from the triceps brachii. This fact could partially account for the smaller difference between genders for movement time during the first ninety degrees of forearm flexion. The delay, in the second triceps burst, allowed for the longer acceleration time and, consequently, the decreased movement time. The delay also had implications for the reduction in accuracy, the women did not seem able to couple the delay, in the second triceps burst, with a contraction sufficient enough to brake the forearm near ninety degrees of flexion.

The duration of the first biceps burst was also subject to gender influences, as the women required a longer biceps duration to overcome the initial inertia of the forearm. The marked difference in flexion strength (27.16 lbs. for the women and 50.19 lbs. for the men) may be the ultimate source for the difference between genders in the duration of the first biceps burst.

Practice or days effects were revealed for the time to the second biceps burst during the first ninety degrees of flexion; the duration of the second triceps burst; and maximal displacement. These criterion measures did not reveal gender influences, however, they were sensitive to inertial loading. As the inertial load increased, an increase in the duration of the second burst from the triceps brachii was necessary to brake the forearm.

Inertial loading influences were revealed in the following criterion measures, to maximal displacement: biceps motor time, second triceps motor time, first biceps burst to second triceps burst latency, second triceps burst to zero acceleration latency, the ratio between first biceps burst EMG and second triceps burst EMG, and accuracy. These measures were critical to the onset of limb movement and the cessation of limb movement.

The variance analysis of practice day 1 and 4 yielded non significant differences for gender, days, and load conditions for: time to maximal acceleration, biceps silent period, first triceps motor time, first biceps burst to first triceps burst latency, second triceps burst to maximal acceleration, slope of the first biceps burst EMG, slope of the second triceps burst EMG, and the ratio between the total biceps EMG and the total triceps EMG. This lack of statistical significance should not negate the meaningful changes in first triceps motor time, in first biceps burst to first triceps burst latency, in biceps silent period, in second triceps to maximal acceleration latency, and in the ratio between the total biceps EMG and the total triceps EMG. There were distinct gender differences in the slope of the first biceps burst EMG and in the slope of the second triceps burst EMG.

Baseline Conditions

The variance analysis of the criterion measures, during the first ninety degrees of forearm flexion, established their stability. Previously observed gender and load condition differences were maintained for movement time, acceleration time, and the time to the second triceps burst. Gender differences were isolated for the time to the second biceps burst, indicative of a protracted stabilization period.

In the analysis of the criterion measures to maximal displacement, significant gender differences were observed for the slope of the first biceps burst EMG and the slope of the second triceps burst EMG. Gender and load condition differences continued for movement time, acceleration time, and first biceps duration. Gender differences were revealed for first biceps motor time and second triceps burst duration. Significant day and load condition effects were observed in the following criterion measures: second triceps motor time, first biceps burst to second triceps burst latency, second triceps burst to maximal acceleration latency, and second triceps burst to zero acceleration latency. The single degree of freedom component analysis of the days effect yielded non significant linear components. Therefore, the significant day effects could be attributed to day to day subject variability rather than a lack of stability.

Immunity from gender, day, and load condition effects continued for the time to maximal acceleration, biceps silent period, first triceps motor time, first biceps burst to first triceps burst latency, and the ratio between the total biceps EMG and the total triceps EMG. Accuracy and maximal displacement did not maintain load condition differences over the six experimental days.

Isometric strength measures

The groups differed significantly in isometric flexion and extension expressed force. Non significant day effects were observed following the variance analysis of the practice days in conjunction with high, in excess of r = .86, intraclass reliability coefficients.

The six imposed exercise regimens induced significant levels of fatigue in both genders. The 5/5:0 fatigue regimens induced concurrent fatigue in the women only. As previously stated, this lack of success could be accounted for by the 30 percent difference between extension M.V.C. and flexion M.V.C., in the men.

Influence of induced fatigue

The variance analysis of the criterion measures after the imposition of the fatigue regimens yielded significant gender, load condition, and regimen effects for movement time, during the first ninety degrees of forearm flexion; time to second triceps burst, also during the first ninety degrees of forearm flexion; second triceps duration, to maximal displacement; and the slope of the second triceps burst EMG. Agonist fatigue regimens, 5:5, 5:10, and both 5/5:0 regimens produced a delayed second burst from the triceps brachii which translated into increased movement times. Antagonist fatigue regimens, 5:5 and 5:10, produced earlier and longer second bursts from the triceps brachii with a resultant trend toward decreased movement times.

The imposed fatigue regimens also produced significant changes in movement time to maximal displacement; acceleration time to maximal displacement; first biceps burst to second triceps burst latency; second triceps burst to maximal acceleration; and second triceps burst to zero acceleration latency. Agonist fatigue regimens combined increased acceleration time, increased latencies for the first biceps burst to second triceps burst, decreased latencies for second triceps to zero acceleration latency, and increased latencies for second triceps to maximal acceleration with resultant increased movement times. Antagonist, 5:5 and 5:10, fatigue regimens combined decreased acceleration time, decreased latencies for the first biceps burst to second triceps burst, increased latencies for second triceps to zero acceleration, and decreased latencies for second triceps to maximal acceleration with resultant trends toward decreased movement times. All of the criterion measures, which were significantly altered by the imposed fatigue regimens, were directly associated with the second burst from the triceps brachii. Once again establishing the key role of the second triceps burst in the speed of human forearm flexion.

Movement time prediction formulae

A factor analysis was conducted on the criterion measures, to maximal displacement, including isometric flexion and extension M.V.C. measures. The most heavily loaded variable in each factor and a grouping variable, to account for gender, were submitted to stepwise multiple regression analysis. The resulting predictive equations, for each load condition, are presented in Table 52, 53, and 54. The multiple R^2 (coefficient of determination) is an expression of the portion of movement time variance determined by or accounted for by the predictors chosen in the analysis. The residual $(1-R^2)$ is that portion of the variance not accounted for by the selected variables and, therefore, attributable to other variables. The predictive value of acceleration time alone ranged from $r = .88$ to $r = .92$ or 77 to 85 percent of the variance associated with movement time to maximal displacement. Although, the gender variable was selected third in the prediction formulae for load condition 1 and 2, its inclusion in the prediction formulae did not attain significance at the .05 level of confidence.

TABLE 52

PREDICTION OF MAXIMUM SPEED OF HUMAN FOREARM FLEXION FOR LOAD 0 FROM SELECTED CRITERION MEASURES, N = 24.

VARIABLE ORDER		
1. ACCELERATION TIME (A)	MULTIPLE R = .88401	MULTIPLE R^2 = .78148
Equation: M.T. = -13.751 + 1.409(A)		
1. ACCELERATION TIME (A)	MULTIPLE R = .92111	MULTIPLE R^2 = .84844
2. FIRST TRICEPS MOTOR TIME (T)		
Equation: M.T. = -29.566 + 1.344(A) + .503(T)		
1. ACCELERATION TIME (A)	MULTIPLE R = .94917	MULTIPLE R^2 = .90092
2. FIRST TRICEPS MOTOR TIME (T)		
3. BICEPS EMG/TRICEPS EMG (BT)		
Equation: M.T. = -16.041 + 1.224(A) + .452(A) + 1.657(BT)		
1. ACCELERATION TIME (A)	MULTIPLE R = .95220	MULTIPLE R^2 = .90669
2. FIRST TRICEPS MOTOR TIME (T)		
3. BICEPS EMG/TRICEPS EMG (BT)		
4. FLEXION M.V.C. (F)		
Equation: M.T. = -.0037 + 1.160(A) + .426(T) + 1.660(BT) - .137(F)		
1. ACCELERATION TIME (A)	MULTIPLE R = .95279	MULTIPLE R^2 = .90782
2. FIRST TRICEPS MOTOR TIME (T)		
3. BICEPS EMG/TRICEPS EMG (BT)		
4. FLEXION M.V.C. (F)		
5. GENDER (0=Women, 1=Men)		
Equations: Women M.T. = -2.749 + 1.176(A) + .464(T) + 1.674(BT) - .213(F) + 2.87(0)		
Men M.T. = -2.749 + 1.176(A) + .464(T) + 1.674(BT) - .213(F) + 2.87(1)		

TABLE 53

PREDICTION OF MAXIMUM SPEED OF HUMAN FOREARM FLEXION FOR LOAD 1 FROM SELECTED CRITERION MEASURES, N = 24.

VARIABLE ORDER		
1. ACCELERATION TIME (A)	MULTIPLE R = .91724	MULTIPLE R^2 = .84133
Equation: M.T. = -19.677 + 1.498(A)		
1. ACCELERATION TIME (A)	MULTIPLE R = .94066	MULTIPLE R^2 = .88483
2. BICEPS EMG/TRICEPS EMG (BT)		
Equation: M.T. = -11.869 + 1.392(A) + 1.713(BT)		
1. ACCELERATION TIME (A)	MULTIPLE R = .94826	MULTIPLE R^2 = .89919
2. BICEPS EMG/TRICEPS EMG (BT)		
3. GENDER (0=Women, 1=Men)		
Equations: Women M.T. = 21.924 + 1.202(A) + 1.733(BT) - 9.293(0)		
Men M.T. = 21.924 + 1.202(A) + 1.733(BT) - 9.293(1)		
1. ACCELERATION TIME (A)	MULTIPLE R = .95124	MULTIPLE R^2 = .90487
2. BICEPS EMG/TRICEPS EMG (BT)		
3. GENDER (0=Women, 1=Men)		
4. TRICEPS (2B) TO ZERO ACC. LATENCY (TZ)		
Equations: Women M.T. = 5.885 + 1.228(A) + 1.847(BT) - 7.102(0) + .154(TZ)		
Men M.T. = 5.885 + 1,228(A) + 1.847(BT) - 7.102(1) + .154(TZ)		

TABLE 54

PREDICTION OF MAXIMUM SPEED OF HUMAN FOREARM FLEXION FOR LOAD 2 FROM SELECTED CRITERION MEASURES, N = 24.

VARIABLE ORDER		
1. ACCELERATION TIME (A)	MULTIPLE R = .92289	MULTIPLE R^2 = .85173
Equation: M.T. = -11.374 + 1.457(A)		
1. ACCELERATION TIME (A)	MULTIPLE R = .94872	MULTIPLE R^2 = .90007
2. BICEPS EMG/TRICEPS EMG (BT)		
Equation: M.T. = -2.158 + 1.356(A) + 1.658(BT)		
1. ACCELERATION TIME (A)	MULTIPLE R = .95415	MULTIPLE R^2 = .91040
2. BICEPS EMG/TRICEPS EMG (BT)		
3. GENDER (0=Women, 1=Men)		
Equations: Women M.T. = 30.256 + 1.202(A) + 1.649(BT) - 9.405(0)		
Men M.T. = 30.256 + 1.202(A) + 1.649(BT) - 9.405(1)		
1. ACCELERATION TIME (A)	MULTIPLE R = .95622	MULTIPLE R^2 = .91435
2. BICEPS EMG/TRICEPS EMG (BT)		
3. GENDER (0=Women, 1=Men)		
4. BICEPS(1B) TO TRICEPS(2B) LATENCY (BTL)		
Equations: Women M.T. = 34.012 + 1.190(A) + 1.576(BT) - 8.883(0) - .067(BTL)		
Men M.T. = 34.012 + 1.190(A) + 1.576(BT) - 8.883(1) - .067(BTL)		

The predictive value of the ratio between the total biceps EMG and the total triceps EMG was revealed, under all load conditions. The inclusion of this criterion measure, as the second or third variable, accounted for a significant portion of the variance associated with movement time and, therefore, increased the predictive power of the formula.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Introduction

As long as speed is used as a criterion of excellence in human endeavors, the identification of the correlates of maximum human speed will continue to intrigue researchers. Early investigators saught to establish the preeminence of Newtonian physics over human speed movements, the supposition was without experimental support. The isometric strength of the muscle was not the determinant of the speed of the muscle, perhaps some combination of neuromotor coordination mechanisms held the key.

Research into skill acquisition, muscle synergy, and the effects of fatigue created windows into the neuromotor mechanisms of human speed. The investigations of Lagasse (53, 54) and Wolcott (103) were carefully considered in the design of this investigation. The major focus of this investigation was to enhance the predictability of the maximum speed of human forearm flexion, under resisted and unresisted conditions, by incorporating a class B movement with the maximized role of the second burst of bioelectric activity from the triceps brachii. This investigation also saught to address the dearth of information available on women, in this research area, and to elucidate differences, if any, between genders.

Methodology

Twenty-four subjects, twelve men and twelve women, were monitored during each of ten testing sessions for:

1. bioelectric activity from the biceps brachii and the triceps brachii;
2. maximum speed of forearm flexion
   a. unresisted (L0)
   b. resisted, two conditions (L1, L2);
3. acceleration time
4. maximum voluntary isometric elbow flexion strength
   a. fast maximum voluntary isometric elbow flexion strength; and
5. maximum voluntary isometric elbow extension strength
   a. fast maximum voluntary isometric elbow extension strength.

Baseline measures recorded during each session included the following parameters:

1. movement time, to maximal displacement
2. movement time, during the first ninety degrees of forearm flexion
3. biceps motor time
4. triceps motor time
5. time to zero acceleration
6. biceps to triceps latency

7. time to the second burst of the biceps and triceps brachii
8. M.V.C. (isometric) elbow flexion
9. M.V.C. (isometric) elbow extension

Acceptable degrees of reliability and stability were established for the criterion measures.

On the last six testing session, following baseline measurements, one of six isometric fatigue regimens was imposed. Upon completion of the fatigue regimen, strength assessments and three trials, at each resistance load, were recorded.

Results

In response to the questions addressed in Chapter I, the statistical analysis presented in Chapter IV yielded the following answers:

1. Significant gender differences were observed for movement time, during the first ninety degrees of forearm flexion; movement time to maximal displacement; acceleration time to maximal displacement; acceleration time, during the first ninety degrees of flexion; time to second biceps burst (90°); time to second triceps burst (90°); first biceps motor time; first biceps duration; second triceps duration; slope for the first biceps burst EMG; and slope for the second triceps burst EMG.

2. The two inertial load conditions elicited significant alterations in movement time (90°), acceleration time (90°), time to second biceps burst (90°), time to second triceps burst (90°), movement time to maximal displacement, acceleration time to maximal displacement first biceps motor time, first biceps duration, second triceps motor time, second triceps duration, first biceps burst to second triceps burst latency, second triceps burst to maximal acceleration latency, second triceps burst to zero acceleration latency, slope for the second triceps burst EMG, and the ratio between the first biceps burst EMG and the second triceps burst EMG.

3. Four practice days induced significant changes in movement time (90°), time to second biceps burst (90°), movement time to maximal displacement, second triceps duration, maximal displacement, and accuracy.

4. The six isometric fatigue regimens induced significant changes in movement time (90°), acceleration time to maximal displacement, second triceps duration, time to second triceps burst (90°), first biceps burst to second triceps burst latency, second triceps burst to maximal acceleration latency, second triceps burst to zero acceleration latency, and slope of the second triceps burst EMG.

5. Prediction formulae established the role of acceleration time as the most powerful predictor for movement time to maximal displacement, under Load 0 (R^2 = .78), Load 1 (R^2 = .84), and Load 2 (R^2 = .85).

Conclusions

Based on the results presented in this investigation, the following conclusions may be drawn:

1. Gender differences exist within the neuromotor mechanisms associated with the speed of human forearm flexion, under resisted and unresisted load conditions.
2. Gender differences persisted while sensorimotor performance deteriorated under the influence of imposed isometric fatigue.
3. Inertial loading required adjustments and compensations within the neuromotor mechanism associated with the speed of human forearm flexion.
4. Acceleration time is an excellent predictor of movement time to maximal displacement, under resisted and unresisted load conditions.
5. Concurrent isometric fatigue can be induced in agonist and antagonist musculature with varying degrees of success.
6. Isometrically induced fatigue significantly altered the timing of the second burst of bioelectric activity

from the triceps brachii and all coordination mechanisms associated with the second burst from the triceps brachii.

Recommendations

The findings of the present investigation suggest several avenues for further inquiry. A measurement and analysis technique to ascertain the firing frequency exhibited by the biceps and tricep brachii during forearm flexion. Gender differences, practice effects, and the influence of fatigue on firing frequency would reveal additional information on the neuromotor coordination mechanisms of human forearm flexion.

An expanded examination of the gender differences, observed in the present investigation, is deemed prudent. The selection of subjects by expressed force capabilities or by athletic specialty, power or endurance, should further isolate the source of gender differences. Similar investigations with the aged and the young, of both genders, serving as subjects should create yet another window on the neuromotor mechanisms of human speed by exploring the maturation process. The response of the neuromotor coordination mechanisms, in the above named populations, to isotonic fatigue is another avenue for further research. Investigations into the possible role of volition on neuromotor coordination mechanisms via biofeedback technique is yet another avenue for further research.

The further elucidation of the correlates of human speed was the intent of the present investigation. For as the knowledge is increased and substantiated it is hoped those efficient in movement will be made more efficient and those inefficient will be made efficient.

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AD-A168 165 COORDINATION MECHANISM IN FAST HUMAN MOVEMENTS - EXPERIMENTAL AND MODELLING STUDIES VOLUME 2(U) MASSACHUSETTS UNIV AMHERST W KROLL ET AL. FEB 82 3/5

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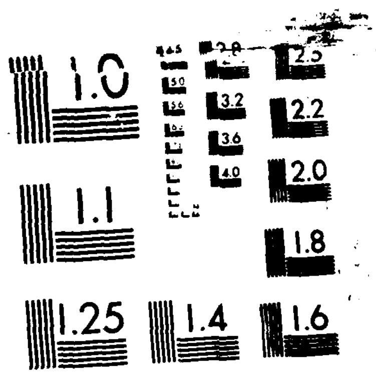

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APPENDIX A

SAMPLE SIZE ESTIMATION

Case Four Formula: Cohen (23, pp. 46-50)

where $d = \frac{d'_4}{\sqrt{1 - r}}$ and $d'_4 = \frac{|m_x - m_y|}{\sigma}$

1. Total Movement Time (msec.) for Baseline Condition Load 1 versus Fatigue (n=12)

$m_x - m_y$ = 14.22 (10% baseline mean value)
SD = 15.88
r = .96
d'_4 = .90
d = 4.50
alpha = .05 power $\leq$ 80 = 9 subjects.

2. Total Movement Time (msec.) for Baseline Condition Load 2 versus Fatigue (n=12)

$m_x - m_y$ = 15.72 (10% baseline mean value)
SD = 17.27
r = .97
d'_4 = .91
d = 5.35
alpha = .05 power $\leq$ 80 = 9 subjects

3. Total Movement Time (msec.) for Baseline Condition Load 3 versus Fatigue (n=12)

$m_x - m_y$ = 18.14 (10% baseline mean value)
SD = 18.38
r = .97
d'_4 = .99
d = 5.82
alpha = .05 power $\leq$ 80 = 9 subjects

POST MORTEM ANALYSIS

Case Four Formula: Cohen (23, pp. 46-50)

where $d = \frac{d'_4}{\sqrt{1-r}}$ and $d'_4 = \frac{M_X - M_Y}{\sigma}$

		Load 0		
1. Movement Time		Women	Men	
$m_X - m_Y$	=	20.3	17.9	(10% baseline mean)
SD	=	3.08	1.46	
r	=	.59	.79	
d'_4	=	6.59	12.26	
d	=	10.29	26.75	
alpha	=	.05	.05	
Power	=	90	90	

		Load 1		
2. Movement Time		Women	Men	
$m_X - m_Y$	=	23.1	19.1	(10% baseline mean)
SD	=	2.57	2.93	
r	=	.86	.95	
d'_4	=	8.99	6.52	
d	=	24.02	29.15	
alpha	=	.05	.05	
Power	=	90	90	

		Load 2		
3. Movement Time		Women	Men	
$m_X - m_Y$	=	27.4	22.6	(10% Baseline mean)
SD	=	3.85	3.48	
r	=	.96	.88	
d'_4	=	7.12	6.49	
d	=	35.58	18.75	
alpha	=	.05	.05	
Power	=	90	90	

APPENDIX B

RADIUS OF GYRATION FORMULA

Plagenhoef (73):

$$\text{Mass (MO)} = \frac{\text{Body Weight (kg)} \times 2.2\%}{1.14}$$

$$\text{Kp}^* = 82.7\% \times \text{distance from elbow to ulnar styloid (cm)}$$

$$\text{MoI}^{**} = \text{MOKp}^2$$

$$\text{Load}_1\text{Kp}_1\text{(cm)} = \sqrt{\frac{2.1\ \text{MoI}}{\text{MO} + \text{M1}}}$$

$$\text{Load}_2\text{Kp}_2\text{(cm)} = \sqrt{\frac{6.1\ \text{MoI}}{\text{MO} + \text{M2}}}$$

*radius of gyration
**moment of inertia

Constants

2.2% = hand and forearm percentage of body weight
1.14 = specific gravity approximation of hand and forearm
82.7% = location of proximal radius of gyration of forearm and hand
M1 = .45 kg
M2 = .90 kg

APPENDIX D

SPECIFICATIONS FOR THE ELECTROMYOGRAPHIC
RECORDING INSTRUMENTS

1. Beckman Type R Dynograph

Preamplifier #481B

Sensitivity range = 10 mv/cm to 50 v/cm

High input impedance and true differential (minimum of 2 megohms)

Power Amplifier # 482

Zero suppression circuit with a minimum of ten times full scale suppression

EMG Coupler #9852

Frequency response of 5,000 cps

Common mode rejection - greater than 300,00:1 at 60 cps, virtually infinite at DC

Sensitivity: for 1% linearity, muscle potentials of 100 microvolts, and 5% for pulses to 10 microvolts with an integration time of 0.2 seconds

Paper Speed = 250 mm/second

2. Medic Storageline Electromyographic - Model 2210

Preamplifier

Input impedence - 3×10^{9} ohm differential
6×10^{10} ohm commom mode

Commom mode rejection - 100 dB from 10 Hz to 60 Hz with 1K source unbalance

Sweep time: 1 to 200 ms/cm

Sensitivity: 10 mv/cm - 50 v/cm

Frequency response: 10 Hz - 20kHz

APPENDIX E

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR MOVEMENT TIME TO MAXIMAL DISPLACEMENT OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	49602.71	36.71*
Blocks w/groups (B:G)	2	1351.37	.74
Subjects w/blocks (S:BG)	20	1823.99	5.00**
Days (D)	1	10267.43	24.03*
DG	1	870.45	2.04
DB:G	2	427.31	.64
DS:BG	20	665.14	1.82
Loads (L)	2	41042.08	139.40**
Linear	1	80166.87	272.28**
Quadratic	1	1917.30	6.51
GL	2	1227.87	4.17
BL:G	4	294.43	.46
SL:BG	40	646.83	1.77*
DL	2	407.76	.29
DLG	2	239.57	.66
DLB:G	4	1389.15	3.81*
Error	40	364.59	

$^{**}p < .01$
$^{*}p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR ACCELERATION TIME OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups(G)	1	24175.84	24.24*
Blocks w/groups(B:G)	2	997.22	2.05
Subjects w/blocks(s:BG)	20	487.35	4.37**
Days(D)	1	11.62	.03
DG	1	29.91	.08
DB:G	2	378.91	1.70
DS:BG	20	223.07	2.00
Loads(L)	2	15871.83	39.36**
Linear	1	30245.65	75.00**
Quadratic	1	1498.01	3.71
GL	2	836.94	2.08
BL:G	4	403.29	1.89
SL:BG	40	213.04	1.91
DL	2	20.56	.04
DLG	2	13.32	.12
DLB:G	4	511.66	4.59*
Error	40	111.40	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR TIME TO MAXIMAL ACCELERATION OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups(G)	1	3515.70	10.00
Blocks w/groups(B:G)	2	351.63	.67
Subjects w/blocks(S:BG)	20	528.63	4.14
Days(D)	1	76.68	.19
DG	1	420.11	1.04
DB:G	2	402.88	2.20
DS:BG	20	183.21	1.44
Loads(L)	2	21.30	.10
Linear	1	12.83	.06
Quadratic	1	29.78	.13
GL	2	1082.73	4.88
BL.G	4	221.96	1.45
SL:BG	40	153.31	1.20
DL	2	123.40	.46
DLG	2	26.12	.20
DLB:G	4	267.73	2.10
Error	40	127.49	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR FIRST BICEPS MOTOR TIME OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	3363.13	4.15
Block w/groups (B:G)	2	809.77	1.26
Subjects w/blocks (S:BG)	20	641.77	5.88**
Days (D)	1	428.11	2.15
DG	1	926.83	4.66
DB:G	2	198.83	.78
DS:BG	20	254.40	2.33*
Loads (L)	2	9609.20	34.87**
Linear	1	19180.63	69.61**
Quadratic	1	37.77	.14
GL	2	75.98	.28
BL:G	4	275.55	1.32
SL:BG	40	208.40	1.91*
DL	2	72.37	1.40
DLG	2	61.98	.57
DLB:G	4	51.67	.47
Error	40	109.11	

**$p < .01$

* $p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR FIRST BICEPS DURATION OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	44933.05	53.40*
Blocks w/groups (B:G)	2	841.38	.54
Subjects w/blocks (S:BG)	20	1556.52	7.11**
Days (D)	1	235.44	.92
DG	1	1459.81	5.73
DB:G	2	254.67	.99
DS:BG	20	258.35	1.18
Loads (L)	2	8614.67	15.61*
Linear	1	17228.65	31.22**
Quadratic	1	.68	.00
GL	2	509.15	.92
BL:G	4	551.88	.52
SL:BG	40	1061.47	4.85**
DL	2	450.72	2.07
DLG	2	124.77	.57
DLB:G	4	217.53	.99
Error	40	218.77	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR BICEPS SILENT PERIOD OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	368.42	.06
Blocks w/groups (B:G)	2	5805.60	4.50*
Subjects w/blocks (S:BG)	20	1289.14	2.41**
Days (D)	1	10644.91	7.04
DG	1	20.90	.01
DB:G	2	1511.63	.77
DS:BG	20	1952.30	3.65**
Loads (L)	2	14431.63	5.04
Linear	1	16644.25	5.81
Quadratic	1	12219.01	4.26
GL	2	1146.39	.40
BL:G	4	2865.60	3.09*
SL:BG	40	926.97	1.73
DL	2	2154.32	3.10
DLG	2	155.01	.29
DLB:G	4	694.12	1.30
Error	40	534.68	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR FIRST TRICEPS MOTOR TIME OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	3468.23	.40
Blocks w/groups (B:G)	2	8691.59	3.12
Subjects w/blocks (S:BG)	20	2787.50	5.08**
Days (D)	1	4072.78	4.46
DG	1	1418.78	1.55
DB:G	2	912.50	.88
DS:BG	20	1036.02	1.89*
Loads (L)	2	2080.86	1.53
Linear	1	3510.82	2.59
Quadratic	1	650.91	.48
GL	2	3314.55	2.44
BL:G	4	1356.05	.82
SL:BG	40	1656.05	3.02**
DL	2	84.95	.10
DLG	2	884.71	1.61
DLB:G	4	328.45	.60
Error	40	548.32	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR SECOND TRICEPS MOTOR TIME OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups(G)	1	2619.82	1.02
Blocks w/groups(B:G)	2	2568.48	1.06
Subjects w/blocks(S:BG)	20	2416.90	4.79**
Days(D)	1	9374.27	11.45
DG	1	50.02	.06
DB:G	2	818.84	1.48
DS:BG	20	515.50	1.09
Loads(L)	2	28112.64	24.55**
Linear	1	55273.92	48.27**
Quadratic	1	951.35	.83
GL	2	99.87	.09
BL:G	4	1145.15	.93
SL:BG	40	1229.23	2.44**
DL	2	1308.62	3.30
DLG	2	73.56	.15
DLB:G	4	396.89	.79
Error	40	504.38	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR SECOND TRICEPS DURATION OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	6178.09	2.97
Blocks w/groups (B:G)	2	2077.12	1.26
Subjects w/blocks (S:BG)	20	1646.50	3.70**
Days (D)	1	5083.81	50.84**
DG	1	5.58	.06
DB:G	2	99.99	.20
DS:BG	20	506.62	1.14
Loads (L)	2	3711.50	12.42*
Linear	1	7198.37	24.08*
Quadratic	1	224.63	.75
GL	2	1805.10	6.04
BL:G	4	298.93	.35
SL:BG	40	845.59	1.90*
DL	2	49.32	.08
DLG	2	720.66	1.62
DLB:G	4	621.35	1.40
Error	40	445.15	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	1245.33	.23
Blocks w/groups (B:G)	2	7321.78	3.20
Subjects w/blocks (S:BG)	20	1664.99	3.13**
Days (D)	1	2633.31	4.00
DG	1	201.76	.31
DB:G	2	657.99	.74
DS:BG	20	887.91	1.67
Loads (L)	2	2425.90	1.48
Linear	1	293.83	.18
Quadratic	1	4557.98	2.78
GL	2	1386.53	.85
BL:G	4	1637.91	1.80
SL:BG	40	908.00	1.71*
DL	2	44.19	.24
DLG	2	470.35	.88
DLB:G	4	184.16	.35
Error	40	532.29	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS FOR FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	50704.91	7.78
Blocks w/groups (B:G)	2	6521.47	4.10*
Subjects w/blocks (S:BG)	20	1588.86	4.17**
Days (D)	1	361.54	.71
DG	1	749.07	1.47
DB:G	2	508.38	.91
DS:BG	20	558.69	1.47
Loads (L)	2	27507.28	13.75*
Linear	1	51307.85	25.65**
Quadratic	1	3693.70	1.85
GL	2	2875.53	1.44
BL:G	4	2000.64	1.67
SL:BG	40	1194.60	3.14**
DL	2	317.62	1.20
DLG	2	30.78	.08
DLB:G	4	264.80	.70
Error	40	380.94	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	12596.70	4.77
Blocks w/groups (B:G)	2	2638.17	2.34
Subjects w/blocks (S:BG)	20	1126.76	3.33**
Days (D)	1	11.62	.01
DG	1	3.76	.00
DB:G	2	813.52	1.60
DS:BG	20	508.21	1.50
Loads (L)	2	4926.16	5.99
Linear	1	5188.07	6.31
Quadratic	1	4664.25	5.67
GL	2	145.59	.18
BL:G	4	822.03	1.04
SL:BG	40	792.01	2.34
DL	2	862.87	5.38
DLG	2	203.87	.60
DLB:G	4	160.53	.47
Error	40	338.63	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	257.28	.15
Blocks w/groups (B:G)	2	1682.24	2.24
Subjects w/blocks (S:BG)	20	751.26	2.20*
Days (D)	1	242.53	.55
DG	1	287.75	.65
DB:G	2	442.44	1.98
DS:BG	20	223.49	.65
Loads (L)	2	5851.67	10.14*
Linear	1	11120.89	19.27*
Quadratic	1	528.46	1.01
GL	2	227.86	.39
BL:G	4	577.04	.87
SL:BG	40	659.64	1.93
DL	2	809.65	2.71
DLG	2	153.86	.45
DLB:G	4	297.88	.87
Error	40	341.36	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR MAXIMAL DISPLACEMENT OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	675.48	4.52
Blocks w/groups (B:G)	2	149.58	1.54
Subjects w/blocks (S:BG)	20	97.24	2.81**
Days (D)	1	167.14	23.32*
DG	1	194.65	27.16*
DB:G	2	7.17	.12
DS:BG	20	57.41	1.66
Loads (L)	2	78.93	7.35*
Linear	1	157.75	14.69*
Quadratic	1	.12	.01
GL	2	22.93	2.14
BL:G	4	10.74	.24
SL:BG	40	44.14	1.28
DL	2	4.69	.08
DLG	2	4.38	.13
DLB:G	4	60.19	1.74
Error	40	34.61	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR THE SLOPE OF THE FIRST BICEPS BURST EMG OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	401.74	10.51
Blocks w/groups (B:G)	2	38.23	1.80
Subjects w/blocks (S:BG)	20	21.26	1.93*
Days (D)	1	6.24	.71
DG	1	3.42	.39
DB:G	2	8.82	.92
DS:BG	20	9.55	.87
Loads	2	9.79	.82
Linear	1	.45	.04
Quadratic	1	19.12	1.60
GL	2	11.27	.94
BL:G	4	11.94	.99
SL:BG	40	12.00	1.09
DL	2	10.50	.88
DLG	2	10.62	.96
DLB:G	4	11.92	1.08
Error	40	11.02	

**$p < .01$

* $p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR THE SLOPE OF THE SECOND TRICEPS BURST EMG OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	1121.30	8.68
Blocks w/groups (B:G)	2	129.15	.94
Subjects w/blocks (S:BG)	20	137.89	2.62**
Days	1	646.39	8.12
DG	1	199.54	2.51
DB:G	2	79.57	.92
DS:BG	20	86.04	1.64
Loads	2	438.09	4.99
Linear	1	628.48	7.15
Quadratic	1	247.70	2.82
GL	2	113.76	1.29
BL:G	4	87.85	1.45
SL:BG	40	60.75	1.16
DL	2	135.91	7.43*
DLG	2	30.76	.58
DLB:G	4	18.29	.35
Error	40	52.59	

**$p < .01$

* $p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR THE RATIO BETWEEN FIRST BICEPS BURST EMG AND SECOND TRICEPS BURST EMG OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	13943.48	.78
Blocks w/groups (B:G)	2	17968.56	1.09
Subjects w/blocks (S:BG)	20	16543.85	.95
Days (D)	1	9583.59	.79
DG	1	2962.17	.24
DB:G	2	12204.06	.72
DS:BG	20	16992.57	.98
Loads	2	209171.77	16.45**
Linear	1	417766.90	32.85**
Quadratic	1	576.64	.05
GL	2	23344.82	1.84
BL:G	4	12715.99	1.16
SL:BG	40	10942.70	.63
DL	2	22958.92	8.35*
DLG	2	34391.21	1.98
DLB:G	4	2748.54	.16
Error	40	17399.30	

**$p < .01$
* $p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR THE RATIO BETWEEN TOTAL BICEPS EMG AND TOTAL TRICEPS EMG OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	44.36	.13
Blocks w/groups (B:G)	2	347.23	2.85
Subjects w/blocks (S:BG)	20	121.69	2.34*
Days (D)	1	632.27	7.67
DG	1	30.73	.37
DB:G	2	82.46	.70
DS:BG	20	117.55	2.26*
Loads (L)	2	309.11	2.02
Linear	1	594.86	3.89
Quadratic	1	23.36	.15
GL	2	4.79	.03
BL:G	4	152.78	3.63*
SL:BG	40	42.14	.81
DL	2	151.44	3.25
DLG	2	3.05	.06
DLB:G	4	46.62	.90
Error	40	51.98	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR ACCURACY OVER PRACTICE DAYS 1 AND 4, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups(G)	1	662.46	4.62
Blocks w/groups(B:G)	2	143.53	1.48
Subjects w/blocks(S:BG)	20	96.72	2.86
Days(D)	1	163.80	20.95*
DG	1	198.29	25.36*
DB:G	2	7.82	.14
DS:BG	20	57.89	1.71
Loads(L)	2	75.19	6.05
Linear	1	150.10	12.08*
Quadratic	1	.27	.02
GL	2	21.56	1.73
BL:G	4	12.43	.29
SL:BG	40	43.46	1.29
DL	2	5.24	.09
DLG	2	4.04	.12
DLB:G	4	58.55	1.73
Error	40	33.82	

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR MOVEMENT TIME FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER PRACTICE DAYS, N = 24.

Source	Degrees of Freedom		Mean Square		F Ratio	
Groups (G)	1		142691.54		14.49**	
S:G	22		9849.45			
Days (D)	3		4015.46		6.68**	
Linear		1		10853.45		18.05**
Quadratic		1		970.71		1.61
Cubic		1		222.22		.37
DG	3		1458.67		2.43	
DS:G	66		601.20			
Loads (L)	2		159088.06		406.90**	
Linear		1		305090.52		780.32**
Quadratic		1		13085.61		33.47**
LG	2		6539.09		16.72**	
LS:G	44		390.98			
Trials (T)	2		548.93		9.43**	
Linear		1		1006.48		17.29**
Quadratic		1		91.39		1.57
TG	2		27.89		.48	
TS:G	44		58.23			
DL	6		157.58		1.46	
DLG	6		98.10		.91	
DLS:G	132		108.06			
DT	6		30.59		.87	
DTG	6		30.66		.87	
DTS:G	132		35.11			
LT	4		66.50		1.25	
LTG	4		28.18		.53	
LTS:G	88		53.14			
DLT	12		56.65		1.39	
DLTG	12		58.96		1.44	
DLTS:G	264		40.88			

$^{**}p < .01$
$^{*}\ p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR ACCELERATION TIME FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER PRACTICE DAYS, N = 24.

Source	Degrees of Freedom		Mean Square		F Ratio	
Groups (G)	1		20697.63		4.94*	
S:G	22		4188.83			
Days (D)	3		699.72		1.98	
Linear		1		208.38		.59
Quadratic		1		1709.72		4.84*
Cubic		1		181.06		.51
DG	3		144.86		.41	
DS:G	66		353.28			
Loads (L)	2		53771.61		164.33**	
Linear		1		104380.15		318.99**
Quadratic		1		3163.07		9.67**
LG	2		79.35		.24	
LS:G	44		327.22			
Trials (T)	2		79.29		1.87	
Linear		1		56.06		1.33
Quadratic		1		102.52		2.42
TG	2		109.71		2.59	
TS:G	44		42.31			
DL	6		214.19		2.47*	
DLG	6		174.25		2.01	
DLS:G	132		86.78			
DT	6		28.88		.87	
DTG	6		51.29		1.54	
DTS:G	132		33.22			
LT	4		19.73		.76	
LTG	4		57.10		2.21	
LTS:G	88		25.85			
DLT	12		29.96		1.06	
DLTG	12		7.12		.25	
DLTS:G	264		28.27			

**$p < .01$

* $p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR THE TIME TO SECOND BICEPS BURST FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER PRACTICE DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	154740.78	3.33
S:G	22	46411.68	
Days (D)	3	32022.80	6.37**
Linear	1	68424.96	13.61**
Quadratic	1	14801.49	2.94
Cubic	1	12841.94	2.55
DG	3	5719.57	1.14
DS:G	66	5026.98	
Loads (L)	2	168637.56	72.55*
Linear	1	321470.10	138.29**
Quadratic	1	15805.02	6.80*
LG	2	7239.40	3.11
LS:G	44	2324.57	
Trials (T)	2	2558.23	11.37**
Linear	1	4915.76	21.85**
Quadratic	1	200.70	.89
TG	2	1498.79	6.66**
TS:G	44	224.98	
DL	6	508.62	.58
DLG	6	1052.78	1.21
DLS:G	132	871.96	
DT	6	205.88	.79
DTG	6	122.32	.47
DTS:G	132	260.64	
LT	4	269.90	1.01
LTG	4	886.98	3.33
LTS:G	88	266.09	
DLT	12	116.22	.41
DLTG	12	251.76	.88
DLTS:G	264	285.82	

** $p < .01$

* $p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR THE TIME TO SECOND TRICEPS BURST FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER PRACTICE DAYS, N = 24.

Source	Degrees of Freedom		Mean Square		F Ratio	
Groups (G)	1		113057.40		14.21**	
S:G	22		7954.87			
Days (D)	3		1035.93		.99	
Linear		1		822.16		.79
Quadratic		1		1780.78		1.71
Cubic		1		504.85		.48
DG	3		1523.56		1.46	
DS:G	66		1044.06			
Loads (L)	2		57309.83		86.59**	
Linear		1		99958.73		151.03**
Quadratic		1		14660.94		22.15**
LG	2		3674.18		5.55*	
LS:G	44		661.85			
Trials (T)	2		120.31		1.92	
Linear		1		192.75		3.08
Quadratic		1		47.87		.76
TG	2		176.46		2.82	
TS:G	44		62.62			
DL	6		113.73		.45	
DLG	6		289.46		1.15	
DLS:G	132		252.07			
DT	6		74.42		1.28	
DTG	6		12.05		.21	
DTS:G	132		58.28			
LT	4		24.30		.44	
LTG	4		74.93		1.36	
LTS:G	88		55.04			
DLT	12		93.69		1.37	
DLTG	12		66.78		.98	
DLTS:G	264		68.23			

**$p < .01$

* $p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR MOVEMENT TIME FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION, OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	95708.04	22.97**
S:G	22	4166.13	
Days (D)	5	409.84	2.01
Linear	1	1343.27	6.60
Quadratic	1	114.04	.56
Cubic	1	433.82	2.13
DG	5	227.90	1.12
DS:G	110	203.65	
Loads (L)	2	178139.95	648.58**
Linear	1	339073.29	1234.52**
Quadratic	1	17206.61	62.65**
LG	2	3252.97	11.84**
LS:G	44	272.66	
Trials	1	181.41	8.12**
TG	1	.04	.00
TS:G	22	22.33	
DL	10	18.69	.51
DLG	10	44.00	1.20
DLS:G	220	36.77	
DT	5	17.68	1.59
DTG	5	3.54	.32
DTS:G	110	11.13	
LT	2	9.13	.46
LTG	2	25.03	1.25
LTS:G	44	20.06	
DLT	10	8.27	.75
DLTG	10	5.08	.46
DLTS:G	220	11.09	

$^{**}p < .01$
$^{*}p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR ACCELERATION TIME FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom		Mean Square		F Ratio	
Groups (G)	1		37351.26		16.85**	
S:G	22		2216.80			
Days (D)	5		64.31		.34	
Linear		1		1.79		.01
Quadratic		1		.78		.00
Cubic		1		216.45		1.13
DG	5		186.53		.98	
DS:G	110		190.91			
Loads (L)	2		69441.79		252.81**	
Linear		1		133660.31		486.61**
Quadratic		1		5223.27		19.02**
LG	2		740.89		2.70	
LS:G	44		274.68			
Trials (T)	1		25.56		.93	
TG	1		107.39		3.93	
TS:G	22		27.34			
DL	10		61.34		1.0	
DLG	10		89.94		1.47	
DLS:G	220		61.24			
DT	5		11.48		.61	
DTG	5		14.03		.74	
DTS:G	110		18.97			
LT	2		63.50		1.37	
LTG	2		9.14		.20	
LTS:G	44		46.48			
DLT	10		20.55		.66	
DLTG	10		20.45		.66	
DLTS:G	220		31.16			

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR THE TIME TO SECOND BICEPS BURST FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	576755.01	14.66**
S:G	22	39346.62	
Days (D)	5	1837.40	.72
Linear	1	82.91	.03
Quadratic	1	4899.46	1.91
Cubic	1	141.88	.06
DG	5	189.22	.07
DS:G	110	2565.20	
Loads (L)	2	178879.42	98.18**
Linear	1	335916.84	184.39**
Quadratic	1	21824.01	11.98**
LG	2	18099.40	9.93**
LS:G	44	1821.81	
Trials (T)	1	654.87	7.16*
TG	1	67.89	.74
TS:G	22	91.50	
DL	10	340.95	.64
DLG	10	762.00	1.44
DLS:G	220	528.92	
DT	5	87.03	.80
DTG	5	93.94	.86
DTS:G	110	108.64	
LT	2	1697.53	13.07**
LTG	2	73.69	.57
LTS:G	44	129.91	
DLT	10	91.93	.79
DLTS	10	126.36	1.08
DLTS:G	220	116.63	

**$p < .01$
* $p < .05$

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR THE TIME TO SECOND TRICEPS BURST FOR THE FIRST NINETY DEGREES OF FOREARM FLEXION OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	82606.58	11.71**
S:G	22	7054.35	
Days (D)	5	173.53	.36
Linear	1	274.82	.57
Quadratic	1	48.07	.10
Cubic	1	179.18	.37
DG	5	467.09	.97
DS:G	110	480.19	
Loads (L)	2	46545.53	139.11**
Linear	1	82347.48	246.11**
Quadratic	1	10743.57	32.11**
LG	2	4113.53	12.29**
LS:G	44	334.59	
Trials (T)	1	336.25	7.23*
TG	1	378.16	8.13**
TS:G	22	46.53	
DL	10	54.62	.80
DLG	10	68.68	1.00
DLS:G	220	68.59	
DT	5	21.66	.72
DTG	5	21.00	.70
DTS:G	110	30.02	
LT	2	251.92	4.31
LTG	2	7.32	.13
LTS:G	44	58.39	
DLT	10	25.30	1.07
DLTG	10	32.31	1.37
DLTS:G	220	23.61	

**$p < .01$

* $p < .05$

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF MOVEMENT TIME OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Whole Plot	23		
Groups (G)	1	150605.29	55.81*
Blocks w/groups (B:G)	2	2698.76	.54
Subjects w/blocks (S:BG)	20	4954.34	34.47**
Split Plot	120		
Days (D)	5	88.13	.53
Linear	1	119.95	.72
Quadratic	1	65.06	.39
Cubic	1	5.67	.03
DG	5	185.87	1.11
DB:G	10	166.73	.84
DS:BG	100	199.26	1.39**
Split-Split	288		
Loads (L)	2	129810.07	638.95**
Linear	1	249847.91	1229.81**
Quadratic	1	9772.23	48.10**
GL	2	5167.31	25.43**
BL:G	4	203.16	.13
SL:BG	40	1613.01	11.22**
DL	10	110.73	1.74
LDG	10	74.92	.52
BDL:G	20	63.66	.44
Error	200	143.74	

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF ACCELERATION TIME OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom			Mean Square		F Ratio	
Whole Plot	23						
Groups (G)		1		52800.45		24.37*	
Blocks w/groups (B:G)		2		2166.18		1.09	
Subjects w/blocks (S:BG)		20		1990.25		24.23**	
Split Plot	120						
Days (D)		5		116.43		1.52	
Linear			1		324.88		4.24
Quadratic			1		14.03		.18
Cubic			1		25.71		.34
DG		5		116.33		1.52	
DB:G		10		76.61		.66	
DS:BG		100		115.99		1.41**	
Split-Split	288						
Loads (L)		2		45289.86		50.09**	
Linear			1		83146.00		91.97**
Quadratic			1		7433.71		8.22*
GL		2		2353.71		2.60	
BL:G		4		904.09		1.51	
SL:BG		40		600.35		7.31**	
DL		10		50.81		3.35	
LDG		10		54.32		.66	
BDL:G		20		15.17		.18	
Error		200		82.14			

$^{**}p < .01$
$^{*}p < .05$

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF TIME TO MAXIMAL ACCELERATION OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom		Mean Square	F Ratio	
Whole Plot	23				
Groups(G)	1		10151.73	10.60	
Blocks w/groups(B:G)	2		957.77	.77	
Subjects w/blocks(S:BG)	20		1247.02	10.95**	
Split Plot	120				
Days(D)	5		129.77	.49	
Linear		1	130.36		.50
Quadratic		1	325.34		1.24
Cubic		1	8.48		.03
DG	5		277.09	1.06	
DB:G	10		262.55	1.29	
DS:BG	100		203.26	1.78**	
Split-Split	288				
Loads(L)	2		336.15	.23	
Linear		1	194.34		.13
Quadratic		1	477.96		.32
GL	2		4993.02	3.37	
BL:G	4		1480.50	3.49*	
SL:BG	40		423.75	3.72**	
DL	10		85.72	.97	
LDG	10		153.69	1.35	
BDL:G	20		87.99	.77	
Error	200		113.92		

**$p < .01$
* $p < .05$

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF FIRST BICEPS BURST MOTOR TIME OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom		Mean Square		F Ratio	
Whole Plot	23					
Groups (G)	1		13653.23		29.51*	
Blocks w/groups (B:G)	2		462.73		.73	
Subjects w/blocks (S:BG)	20		633.07		7.44**	
Split Plot	120					
Days (D)	5		64.80		.30	
Linear		1		87.18		.40
Quadratic		1		60.02		.28
Cubic		1		41.58		.19
DG	5		118.93		.55	
DB:G	10		217.21		1.62	
DS:BG	100		134.31		1.58**	
Split-Split	288					
Loads (L)	2		28177.42		85.50**	
Linear		1		55834.24		169.42**
Quadratic		1		520.62		1.58
GL	2		826.53		2.51	
BL:G	4		329.56		1.14	
SL:BG	40		288.73		3.39**	
DL	10		50.03		.55	
LDG	10		38.37		.45	
BDL:G	20		91.27		1.07	
Error	200		85.05			

$^{**}p < .01$
$^{*}p < .05$

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE
OF FIRST BICEPS BURST DURATION OVER SIX
EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Whole Plot	23		
Groups (G)	1	73725.53	1117.17**
Blocks w/groups (B:G)	2	65.99	.02
Subjects w/blocks (S:BG)	20	3591.93	18.48**
Split Plot	120		
Days (D)	5	197.38	.89
Linear	1	96.88	.44
Quadratic	1	44.26	.20
Cubic	1	28.17	.13
DG	5	167.40	.75
DB:G	10	222.52	.64
DS:BG	100	345.81	1.78**
Split-Split	288		
Loads (L)	2	41497.20	48.03**
Linear	1	82803.13	95.84**
Quadratic	1	191.26	.22
GL	2	5099.94	5.90
BL:G	4	863.95	.43
SL:BG	40	2019.28	10.39**
DL	10	222.33	1.25
LDG	10	101.90	.52
BDL:G	20	177.64	.91
Error	200	194.35	

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF BICEPS SILENT PERIOD OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom			Mean Square		F Ratio	
Whole Plot	23						
Groups (G)		1		63460.55		4.82	
Blocks w/groups (B:G)		2		13159.49		3.66*	
Subjects w/groups (S:BG)		20		3590.99		10.05**	
Split Plot	120						
Days (D)		5		352.47		.83	
Linear			1		186.49		.44
Quadratic			1		999.05		2.34
Cubic			1		245.88		.58
DG		5		539.26		1.26	
DB:G		10		426.48		.80	
DS:BG		100		535.97		1.50**	
Split-Split	288						
Loads (L)		2		23095.20		5.07	
Linear			1		16984.32		3.73
Quadratic			1		29206.07		6.41
GL		2		15281.84		3.35	
BL:G		4		4557.04		1.50	
SL:BG		40		3028.43		8.48**	
DL		10		158.59		.42	
LDG		10		285.13		.80	
BDL:G		20		377.09		1.06	
Error		200		357.30			

**$p < .01$

* $p < .05$

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF FIRST TRICEPS BURST MOTOR TIME OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom		Mean Square		F Ratio	
Whole Plot	23					
Groups (G)	1		45268.18		1.76	
Blocks w/groups (B:G)	2		25689.04		2.73	
Subjects w/blocks (S:BG)	20		9410.76		25.24**	
Split Plot	120					
Days (D)	5		572.22		.92	
Linear		1		13.12		.02
Quadratic		1		301.49		.49
Cubic		1		1602.55		2.59
DG	5		304.89		.49	
DB:G	10		618.71		1.20	
DS:BG	100		515.42		1.38**	
Split-Split	288					
Loads (L)	2		16244.46		1.56	
Linear		1		31119.30		2.99
Quadratic		1		1369.62		.13
GL	2		4224.84		.41	
BL:G	4		10391.19		2.31	
SL:BG	40		4498.05		12.06**	
DL	10		449.23		.94	
LDG	10		394.50		1.06	
BDL:G	20		479.58		1.29	
Error	200		372.92			

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF SECOND TRICEPS BURST MOTOR TIME OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom			Mean Square	F Ratio
Whole Plot	23				
Groups (G)		1		39313.58	14.24
Blocks w/groups (B:G)		2		2760.81	1.50
Subjects w/blocks (S:BG)		20		1846.07	12.87**
Split Plot	120				
Days (D)		5		393.34	7.92**
Linear			1	442.79	8.91
Quadratic			1	758.19	15.26**
Cubic			1	652.94	13.14**
DG		5		99.44	2.00
DB:G		10		49.69	.21
DS:BG		100		242.02	1.69**
Split-Split	288				
Loads (L)		2		68141.29	26.40**
Linear			1	136272.02	52.80**
Quadratic			1	10.56	.00
GL		2		1338.57	.52
BL:G		4		2580.73	1.82
SL:BG		40		1415.91	9.87**
DL		10		123.08	.64
LDG		10		53.08	.37
BDL:G		20		192.61	1.34
Error		200		143.44	

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF SECOND TRICEPS BURST DURATION OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom		Mean Square		F Ratio	
Whole Plot	23					
Groups (G)	1		33605.08		31.35*	
Blocks w/groups (B:G)	2		1072.02		.23	
Subjects w/blocks (S:BG)	20		4716.72		17.20**	
Split Plot	120					
Days (D)	5		198.29		.55	
Linear		1		.11		.00
Quadratic		1		311.77		.87
Cubic		1		.05		.00
DG	5		388.37		1.08	
DB:G	10		358.98		.86	
DS:BG	100		415.57		1.52**	
Split-Split	288					
Loads (L)	2		18873.17		7.50*	
Linear		1		37145.16		14.76*
Quadratic		1		601.18		.24
GL	2		7311.39		2.91	
BL:G	4		2516.61		1.43	
SL:BG	40		1763.50		6.43**	
DL	10		420.21		2.40*	
LDG	10		170.68		.62	
BDL:G	20		175.37		.64	
Error	200		274.30			

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Whole Plot	23		
Groups (G)	1	17184.53	.57
Blocks w/groups (B:G)	2	30230.33	3.54*
Subjects w/blocks (S:BG)	20	8528.75	23.99**
Split Plot	120		
Days (D)	5	424.19	1.52
Linear	1	549.63	1.97
Quadratic	1	720.40	2.58
Cubic	1	745.40	2.67
DG	5	307.27	1.10
DB:G	10	278.74	.68
DS:BG	100	406.98	1.14
Split-Split	288		
Loads (L)	2	3540.66	.36
Linear	1	556.56	.06
Quadratic	1	6524.76	.67
GL	2	236.41	.02
BL:G	4	9773.44	2.21
SL:BG	40	4415.21	12.42**
DL	10	287.65	1.18
LDG	10	461.70	1.30
BDL:G	20	243.44	.68
Error	200	355.51	

**$p < .01$
* $p < .05$

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF FIRST BICEPS BURST TO SECOND TRICEPS BURST LATENCY OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom		Mean Square	F Ratio	
Whole Plot	23				
Groups (G)	1		98978.97	16.02	
Blocks w/groups (B:G)	2		6178.59	1.39	
Subjects w/blocks (S:BG)	20		4456.38	28.47**	
Split Plot	120				
Days (D)	5		480.58	3.74*	
Linear		1	362.85		2.83
Quadratic		1	885.95		6.90*
Cubic		1	489.61		3.81
DG	5		145.92	1.14	
DB:G	10		128.35	.38	
DS:BG	100		340.69	2.18**	
Split-Split	288				
Loads (L)	2		80659.25	20.93**	
Linear		1	145941.33		37.86**
Quadratic		1	15377.18		3.99
GL	2		7989.10	4.30*	
BL:G	4		3854.42	2.07	
SL:BG	40		1859.94	11.88**	
DL	10		123.96	.99	
LDG	10		130.65	.83	
BDL:G	20		124.68	.80	
Error	200		156.53		

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF SECOND TRICEPS BURST TO MAXIMAL ACCELERATION LATENCY OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom			Mean Square	F Ratio	
Whole Plot	23					
Groups (G)		1		8006.53	3.91	
Blocks w/groups (B:G)		2		2048.84	.91	
Subjects w/blocks (S:BG)		20		2240.69	13.24**	
Split Plot	120					
Days (D)		5		643.09	3.60*	
Linear			1	439.32		2.46
Quadratic			1	1415.10		7.92*
Cubic			1	709.22		3.97
DG		5		215.40	1.21	
DB:G		10		178.62	.50	
DS:BG		100		354.83	2.10**	
Split-Split	288					
Loads (L)		2		10073.59	10.12*	
Linear			1	13756.70		13.82*
Quadratic			1	6390.48		6.42
GL		2		584.26	.59	
BL:G		4		995.47	.85	
SL:BG		40		1171.82	6.92**	
DL		10		185.12	.94	
LDG		10		248.98	1.47	
BDL:G		20		196.31	1.16	
Error		200		169.28		

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF SECOND TRICEPS BURST TO ZERO ACCELERATION LATENCY OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Whole Plot	23		
Groups (G)	1	1610.66	1.36
Blocks w/groups (B:G)	2	1181.74	1.48
Subjects w/blocks (S:BG)	20	797.50	7.94**
Split Plot	120		
Days (D)	5	232.40	4.07*
Linear	1	191.44	3.35
Quadratic	1	536.71	9.40*
Cubic	1	320.32	5.61*
DG	5	50.81	.89
DB:G	10	57.07	.34
DS:BG	100	168.24	1.67**
Split-Split	288		
Loads (L)	2	12584.00	18.36**
Linear	1	24912.10	36.35**
Quadratic	1	255.91	.37
GL	2	915.45	1.34
BL:G	4	685.35	1.00
SL:BG	40	682.12	6.79**
DL	10	125.22	1.14
LDG	10	107.18	1.07
BDL:G	20	110.28	1.10
Error	200	100.45	

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE
OF MAXIMAL DISPLACEMENT OVER SIX EXPERIMENTAL
DAYS, N = 24.

Source	Degrees of Freedom		Mean Square		F Ratio	
Whole Plot	23					
Groups (G)	1		1688.31		2.18	
Blocks w/groups (B:G)	2		600.86		1.18	
Subjects w/blocks (S:BG)	20		507.61		14.17**	
Split Plot	120					
Days (D)	5		66.24		.81	
Linear		1		27.93		.34
Quadratic		1		191.98		2.34
Cubic		1		3.57		.04
DG	5		13.71		.17	
DB:G	10		81.91		1.19	
DS:BG	100		68.75		1.92	
Split-Split	288					
Loads (L)	2		92.00		.57	
Linear		1		160.70		.99
Quadratic		1		23.30		.14
GL	2		55.47		.34	
BL:G	4		162.77		1.69	
SL:BG	40		96.24		2.69	
DL	10		20.36		.62	
LDG	10		25.38		.71	
BDL:G	20		32.70		.91	
Error	200		35.83			

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE
OF SLOPE OF FIRST BICEPS BURST EMG OVER SIX
EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Whole Plot	23		
Groups (G)	1	737.22	517.35**
Blocks w/groups (B:G)	2	1.42	.13
Subjects w/blocks (S:BG)	20	10.58	16.52**
Split Plot	120		
Days (D)	5	.72	1.50
Linear	1	.78	1.62
Quadratic	1	.53	1.10
Cubic	1	.02	.04
DG	5	.98	2.04
DB:G	10	.48	.61
DS:BG	100	.78	1.22*
Split-Split	288		
Loads (L)	2	8.66	.98
Linear	1	15.93	1.80
Quadratic	1	1.39	.16
GL	2	2.86	.32
BL:G	4	8.84	1.34
SL:BG	40	6.58	10.27**
DL	10	.37	.87
LDG	10	.42	.65
BDL:G	20	.42	.66
Error	200	.64	

**$p < .01$
* $p < .05$

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF SLOPE OF SECOND TRICEPS BURST EMG OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom		Mean Square		F [illegible]	
Whole Plot	23					
Groups (G)	1		3178.24		[illegible]*	
Blocks w/groups (B:G)	2		70.14		[illegible]	
Subjects w/blocks (S:BG)	20		263.60		[illegible]**	
Split Plot	120					
Days (D)	5		23.24		[illegible]	
Linear		1		2.67		.06
Quadratic		1		25.78		.61
Cubic		1		5.25		.12
DG	5		16.54		.39	
DB:G	10		42.22		1.78	
DS:BG	100		23.70		2.36**	
Split-Split	288					
Loads (L)	2		341.64		5.24	
Linear		1		553.50		8.49*
Quadratic		1		129.78		1.99
GL	2		68.28		1.05	
BL:G	4		65.18		.95	
SL:BG	40		68.72		6.83**	
DL	10		9.42		.82	
LDG	10		6.15		.61	
BDL:G	20		11.48		1.14	
Error	200		10.06			

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF RATIO BETWEEN FIRST BICEPS BURST AND SECOND TRICEPS BURST OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom		Mean Square	F Ratio	
Whole Plot	23				
Groups (G)	1		4592.43	.13	
Blocks w/groups (B:G)	2		36553.12	.34	
Subjects w/blocks (S:BG)	20		106830.59	34.36**	
Split Plot	120				
Days (D)	5		5688.62	2.29	
Linear		1	20508.94		8.25*
Quadratic		1	860.54		.35
Cubic		1	5026.58		2.02
DG	5		3175.96	1.28	
DB:G	10		2486.76	.73	
DS:BG	100		3405.25	1.10	
Split-Split	288				
Loads (L)	2		512057.84	19.85**	
Linear		1	1019339.74		39.51**
Quadratic		1	4775.95		.19
GL	2		22191.43	.86	
BL:G	4		25796.33	.59	
SL:BG	40		43648.76	14.04	
DL	10		2534.34	1.20	
LDG	10		2760.40	.89	
BDL:G	20		2109.95	.68	
Error	200		3109.32		

**p < .01
* p < .05

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF RATIO BETWEEN TOTAL BICEPS EMG AND TOTAL TRICEPS EMG OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom		Mean Square	F Ratio
Whole Plot	23			
Groups (G)	1		256.64	3.06
Blocks w/groups (B:G)	2		83.97	.44
Subjects w/blocks (S:BG)	20		192.42	26.36**
Split Plot	120			
Days (D)	5		15.91	1.73
Linear		1	.78	.08
Quadratic		1	22.20	2.41
Cubic		1	5.61	.61
DG	5		13.53	1.47
DB:G	10		9.21	.60
DS:BG	100		15.38	2.11**
Split-Split	288			
Loads (L)	2		76.41	.78
Linear		1	146.30	1.50
Quadratic		1	6.51	.07
GL	2		2.80	.03
BL:G	4		97.57	2.64*
SL:BG	40		36.97	5.07**
DL	10		3.43	.53
LDG	10		4.84	.66
BDL:G	20		6.41	.88
Error	200		7.30	

** $p < .01$
* $p < .05$

TABLE

ANALYSIS OF VARIANCE FOR BASELINE CRITERION MEASURE OF ACCURACY OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom		Mean Square		F Ratio	
Whole Plot	23					
Groups (G)	1		1708.42		2.93	
Blocks w/groups (B:G)	2		583.37		1.19	
Subjects w/blocks (S:BG)	20		490.47		14.25**	
Split Plot	120					
Days (D)	5		70.69		.79	
Linear		1		20.30		.23
Quadratic		1		218.88		2.43
Cubic		1		3.73		.04
DG	5		12.92		.14	
DB:G	10		89.96		1.32	
DS:BG	100		68.38		1.99**	
Split-Split	288					
Loads (L)	2		73.15		.49	
Linear		1		129.63		.88
Quadratic		1		16.67		.11
GL	2		59.17		.40	
BL:G	4		147.82		1.53	
SL:BG	40		96.54		2.81	
DL	10		17.24		.60	
LDG	10		23.08		.67	
BDL:G	20		28.69		.83	
Error	200		34.42			

**p < .01
* p < .05

TABLE

REPEATED MEASURES ANALYSIS OF VARIANCE FOR ISOMETRIC STRENGTH MEASURES OVER PRACTICE DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	84290.54	44.80**
Subjects w/groups (S:G)	22	1881.52	
Days (D)	3	40.02	.48
DG	3	12.19	.15
DS:G	66	83.73	
Pre (P)	1	2760.08	159.72**
PG	1	184.95	10.70**
PS:G	22	17.28	
PD	3	52.45	2.60
PDG	3	13.30	.66
PDS:G	66	20.17	
Flexion (F)	1	11690.37	16.08**
FG	1	17404.99	23.93**
FS:G	22	727.24	
FD	3	539.05	6.77**
FDG	3	53.07	.67
FDS:G	66	79.59	
FP	1	38.76	2.47
FPG	1	1.15	.07
FPS:G	22	15.69	
FPD	3	35.38	2.12
FPDG	3	47.81	2.86*
FPDS:G	66	16.72	
MVC (M)	1	133.01	14.14**
MG	1	40.04	4.26
MS:G	22	9.41	
MD	3	5.32	.88
MDG	3	3.03	.50
MDS:G	66	6.07	
MP	1	.06	.01
MPG	1	.20	.04
MPS:G	22	5.04	
MPD	3	29.17	5.52**
MPDG	3	2.03	.38
MPDS:G	66	5.29	
MF	1	80.21	6.04*
MFG	1	102.61	7.72*
MFS:G	22	13.29	
MFD	3	1.59	.21
MFSG	3	12.13	1.62
MFDS:G	66	7.50	

TABLE (con't.)

Source	Degrees of Freedom	Mean Square	F Ratio
MFD	3	1.59	.21
MFDG	3	12.13	1.62
MFDS:G	66	7.50	
MFP	1	4.76	.94
MFPG	1	.61	.12
MFPS:G	22	5.08	
MFPD	3	9.94	1.72
MFPDG	3	10.79	1.86
MFPDS:G	66	5.79	
Trials (T)	1	1.69	.09
TG	1	.09	.00
TS:G	22	18.78	
TD	3	11.67	1.64
TDG	3	1.22	.17
TDS:G	66	7.11	
TP	1	.69	.08
TPG	1	.00	.00
TPS:G	22	9.03	
TPD	3	.97	.14
TPDG	3	19.23	2.81*
TPDS:G	66	6.84	
TF	1	9.22	.84
TFG	1	.00	.00
TFS:G	22	11.04	
TFD	3	9.96	1.45
TFDG	3	14.09	2.05
TFDS:G	66	6.89	
TFP	1	8.69	1.95
TFPG	1	2.38	.53
TFPS:G	22	4.47	
TFPD	3	9.30	1.28
TFPDG	3	1.74	.24
TFPDS:G	66	7.27	
TM	1	6.71	1.69
TMG	1	.12	.03
TMS:G	22	3.96	
TMD	3	4.34	1.10
TMDG	3	2.57	.65
TMDS:G	66	3.94	
TMP	1	.41	.08
TMPG	1	.67	.14
TMPS:G	22	4.88	

TABLE (con't.)

Source	Degrees of Freedom	Mean Square	F Ratio
TMPD	3	6.03	1.54
TMPDG	3	1.11	.28
TMPDS:G	66	3.92	
TMF	1	1.86	.50
TMFG	1	2.08	.55
TMFS:G	22	3.75	
TMFD	3	3.36	.82
TMFDG	3	2.54	.62
TMFDS:G	66	4.09	
TMFP	1	.03	.01
TMFPG	1	2.34	.79
TMFPS:G	22	2.96	
TMFPD	3	2.70	.61
TMFPDS	3	4.04	.91
TMFPDS:G	66	4.42	

**p < .01
* p < .05

TABLE 102

REPEATED MEASURES ANALYSIS OF VARIANCE FOR ISOMETRIC STRENGTH MEASURES OVER SIX EXPERIMENTAL DAYS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	70609.69	25.19**
Subjects w/groups (B:G)	22	2802.85	
Days (D)	5	71.24	1.48
DG	5	161.25	3.35
DS:G	110	48.12	
Flexion (F)	1	16275.09	46.45**
FG	1	9987.56	28.51**
FS:G	22	350.37	
DF	5	21.24	.92
DFG	5	13.05	.57
DFS:G	110	23.07	
M.V.C. (M)	1	125.02	12.15**
MG	1	31.83	3.09
MS:G	22	10.29	
DM	5	.62	.14
DMG	5	2.15	.49
DMS:G	110	4.39	
FM	1	10.41	1.28
FMG	1	6.80	.84
FMS:G	22	8.12	
DFM	5	5.63	1.90
DFMG	5	2.06	69
DFMS:G	110	2.97	
Trials (T)	1	1.57	.20
TG	1	66	.08
TS:G	22	7.98	
DT	5	3.70	.92
DTG	5	1.52	.38
DTS:G	110	4.01	
FT	1	16.89	3.07
FTG	1	5.08	.92
FTS:G	22	5.51	
DFT	5	6.64	1.37
DFTG	5	3.76	.77
DFTS:G	110	4.85	

TABLE 102 (con't.)

Source	Degrees of Freedom	Mean Square	F Ratio
MT	1	.31	.07
MTG	1	1.53	.33
MTS:G	22	4.64	
DMT	5	4.86	1.16
DMTG	5	5.63	1.35
DMTS:G	110	4.17	
FMT	1	.95	.29
FMTG	1	.00	.00
FMTS:G	22	3.26	
DFMT	5	1.83	.58
DFMTG	5	2.81	.88
DFMTS:G	110	3.18	

**p <.01
*p <.05

TABLE 103

VARIANCE ESTIMATES AND INTRACLASS RELIABILITY COEFFICIENTS FOR ISOMETRIC STRENGTH MEASURES OVER SIX EXPERIMENTAL DAYS, N = 24.

MEN	σ^2 DAYS	σ^2 TRIALS	TRUE SCORE	R
FLEXION	13.22	6.18	75.86	.97
EXTENSION	9.27	5.22	58,57	,97
WOMEN				
FLEXION	5,95	2.01	46.68	.98
EXTENSION	5.26	4,53	75.29	.99

TABLE

VARIANCE ANALYSIS FOR THE RATIO BETWEEN THE FIRST BICEPS BURST EMG AND THE SECOND TRICEPS BURST EMG FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups(G)	1	29045.88	1.30
Blocks w/groups(B:G)	2	22324.18	.24
Subjects w/blocks(S:BG)	20	91815.36	10.06**
Days(D)	5	3874.62	.28
Regimens(R)	5	9466.95	1.06
Loads(L)	2	558823.35	30.64**
Load Order(O)	2	2213.24	.20
GD	5	4180.96	.31
GR	5	6823.03	.77
GL	2	6623.82	.36
GO	2	4182.13	.38
BD:G	10	13700.50	1.50
BR:G	10	8910.78	.98
BL:G	4	18237.57	2.00
BO:G	4	11097.52	1.22
Error	352	9128.06	

**$p < .01$
* $p < .05$

TABLE

VARIANCE ANALYSIS FOR THE RATIO BETWEEN TOTAL BICEPS EMG AND TOTAL TRICEPS EMG FOLLOWING FATIGUE REGIMENS, N =24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	568.54	4.79
Blocks w/groups (B:G)	2	118.67	.30
Subjects w/blocks (S:BG)	20	392.73	14.36**
Days (D)	5	17.49	.99
Regimens (R)	5	33.07	1.13
Loads (L)	2	339.81	2.64
Load Order (O)	2	37.79	1.30
GD	5	15.33	.87
GR	5	35.19	1.20
GL	2	16.71	.13
GO	2	63.89	2.20
BD:G	10	17.63	.64
BR:G	10	29.27	1.07
BL:G	4	128.62	4.70**
BO:G	4	29.07	1.06
Error	352	27.35	

**$p < .01$
* $p < .05$

TABLE

VARIANCE ANALYSIS FOR FIRST BICEPS BURST TO FIRST TRICEPS BURST LATENCY FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	56422.60	10.23
Blocks w/groups (B:G)	2	5514.77	1.63
Subjects w/blocks (S:BG)	20	3391.19	2.30**
Days (D)	5	2110.48	2.15
Regimens (R)	5	3321.76	2.47
Loads (L)	2	1346.21	.37
Load Order (O)	2	1098.12	1.41
GD	5	1822.48	1.87
GR	5	986.05	.73
GL	2	469.15	.13
GO	2	2831.01	3.63
BD:G	10	981.69	.66
BR:G	10	1342.85	.91
BL:G	4	3629.72	2.46*
BO:G	4	779.51	.53
Error	352	1477.30	

**p < .01
* p < .05

TABLE

VARIANCE ANALYSIS FOR BICEPS SILENT PERIOD FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	21540.91	.75
Blocks w/groups (B:G)	2	28877.17	12.00**
Subjects w/blocks (S:BG)	20	2405.74	2.50
Days (D)	5	494.11	1.22
Regimens (R)	5	1471.03	2.35
Loads (L)	2	5016.12	2.21
Load Order (O)	2	518.54	.75
GD	5	851.61	2.11
GR	5	948.36	1.51
GL	2	6135.50	2.70
GO	2	784.17	.70
BD:G	10	403.79	.42
BR:G	10	626.56	.65
BL:G	4	2272.35	2.36
BO:G	4	693.54	.72
Error	352	962.91	

**p > .01
* p > .05

TABLE

VARIANCE ANALYSIS FOR ACCURACY FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	1252.26	2.78
Blocks w/groups (B:G)	2	449.76	1.21
Subjects w/blocks (S:BG)	20	371.89	7.26**
Days (D)	5	99.27	1.35
Regimens (R)	5	92.34	1.17
Loads (L)	2	108.12	.96
Load Order (O)	2	3.77	.06
GD	5	81.52	1.11
GR	5	43.46	.55
GL	2	44.33	.39
GO	2	13.02	.21
BD:G	10	73.37	1.43
BR:G	10	79.18	1.55
BL:G	4	112.31	2.19
BO:G	4	60.76	1.19
Error	352	51.20	

$^{**}p < .01$
$^{*}p < .05$

TABLE

VARIANCE ANALYSIS FOR MAXIMAL DISPLACEMENT FOLLOWING FATIGUE REGIMENS, N = 24.

Source	Degrees of Freedom	Mean Square	F Ratio
Groups (G)	1	447.48	.32
Blocks w/groups (B:G)	2	1383.41	3.33
Subjects w/blocks (S:BG)	20	415.85	2.38
Days (D)	5	268.14	1.88
Regimens (R)	5	340.33	1.12
Loads (L)	2	145.31	1.67
Load Order (O)	2	3.78	.05
GD	5	358.34	2.52
GR	5	267.92	.88
GO	2	57.76	.73
BD:G	10	142.48	.82
BR:G	10	302.96	1.74
BL:G	4	86.85	.50
BO:G	4	79.03	.45
Error	352	174.48	

**$p < .01$

* $p < .05$

APPENDIX F

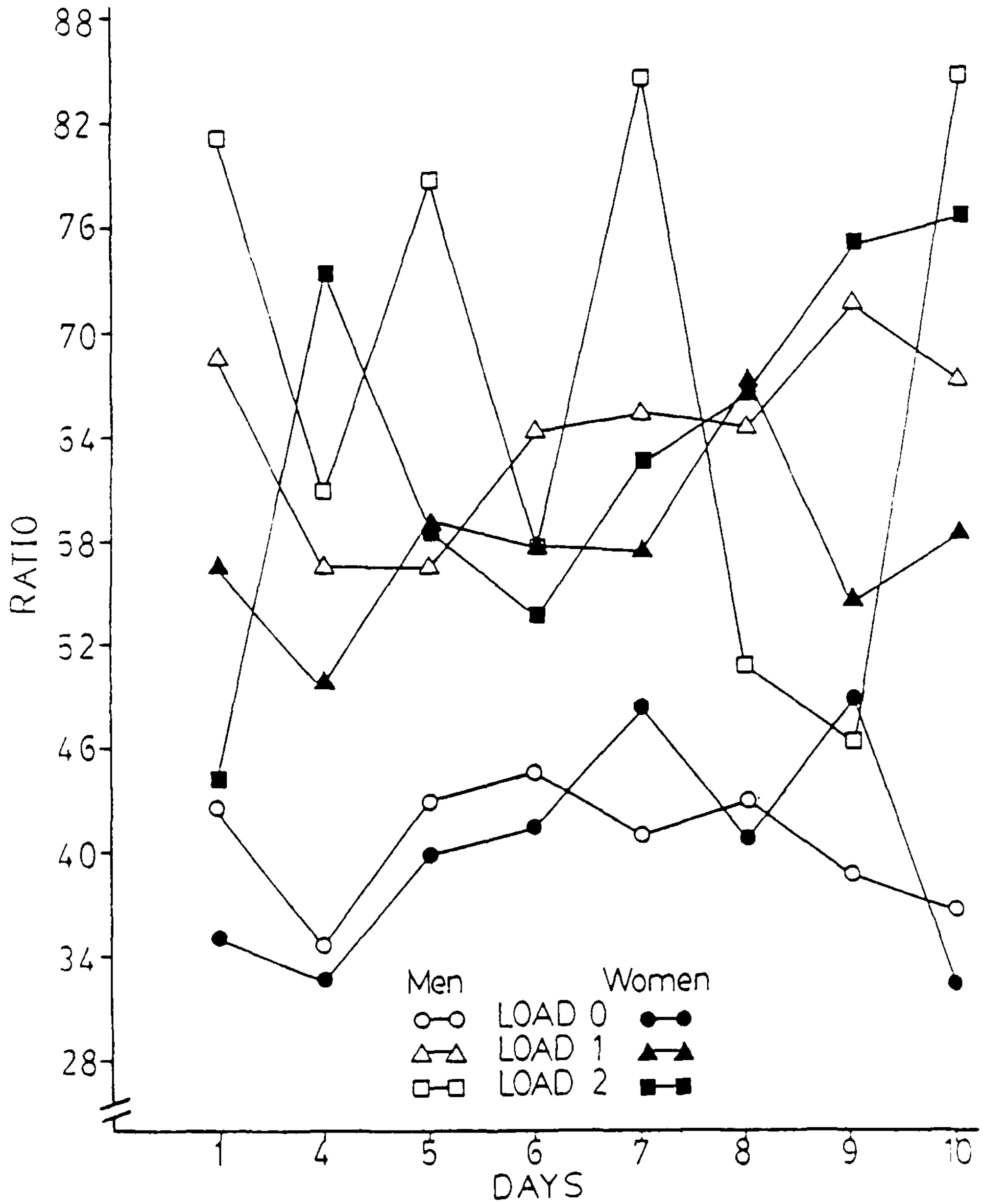

Fig. . Means for the Ratio Between the First Biceps Burst EMG and the Second Triceps Burst EMG across Days 1-15, under all Load Conditions, N = 24.

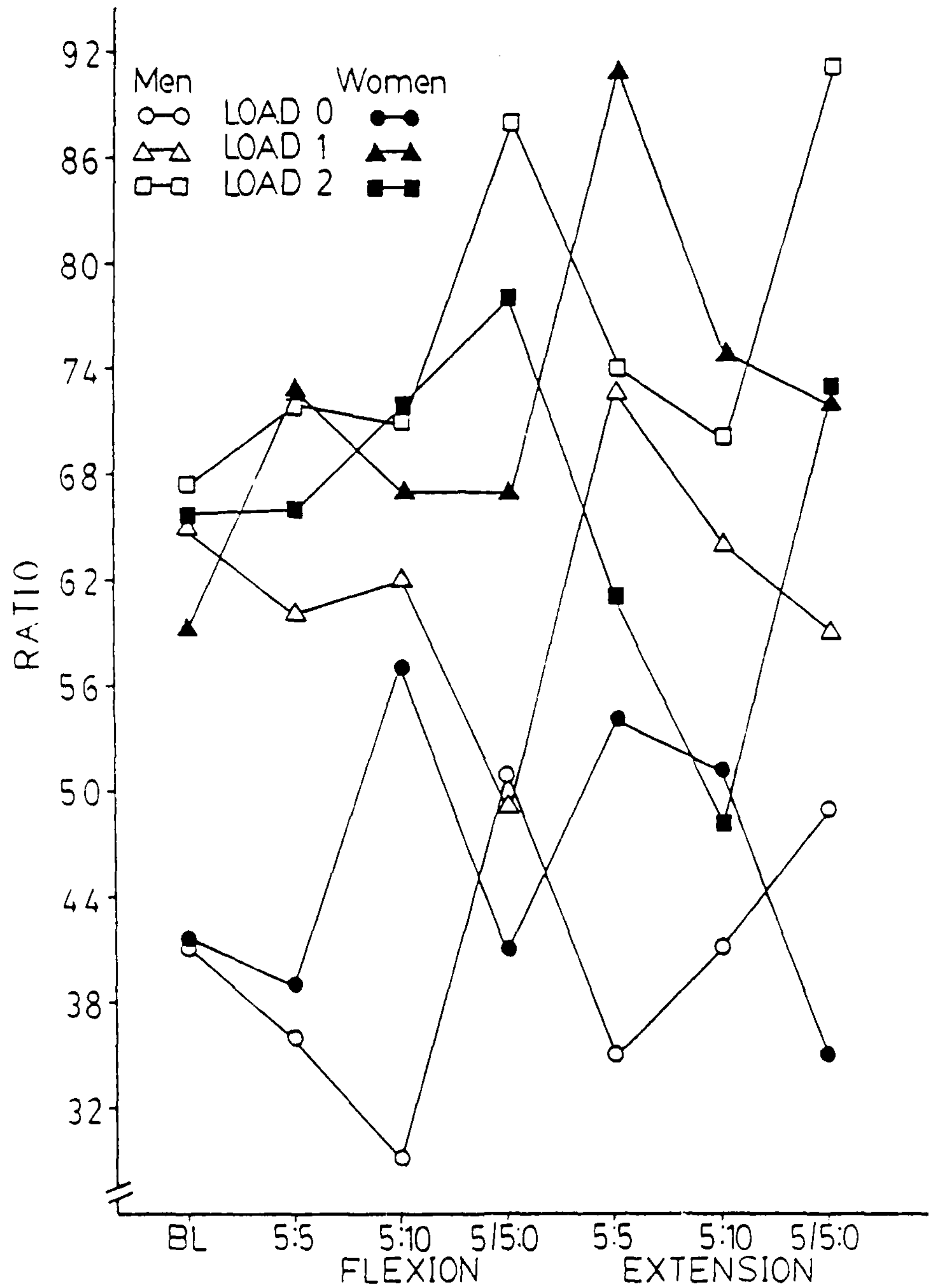

Fig. . Ratio Between the First Biceps Burst EMG and the Second Triceps Burst EMG Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

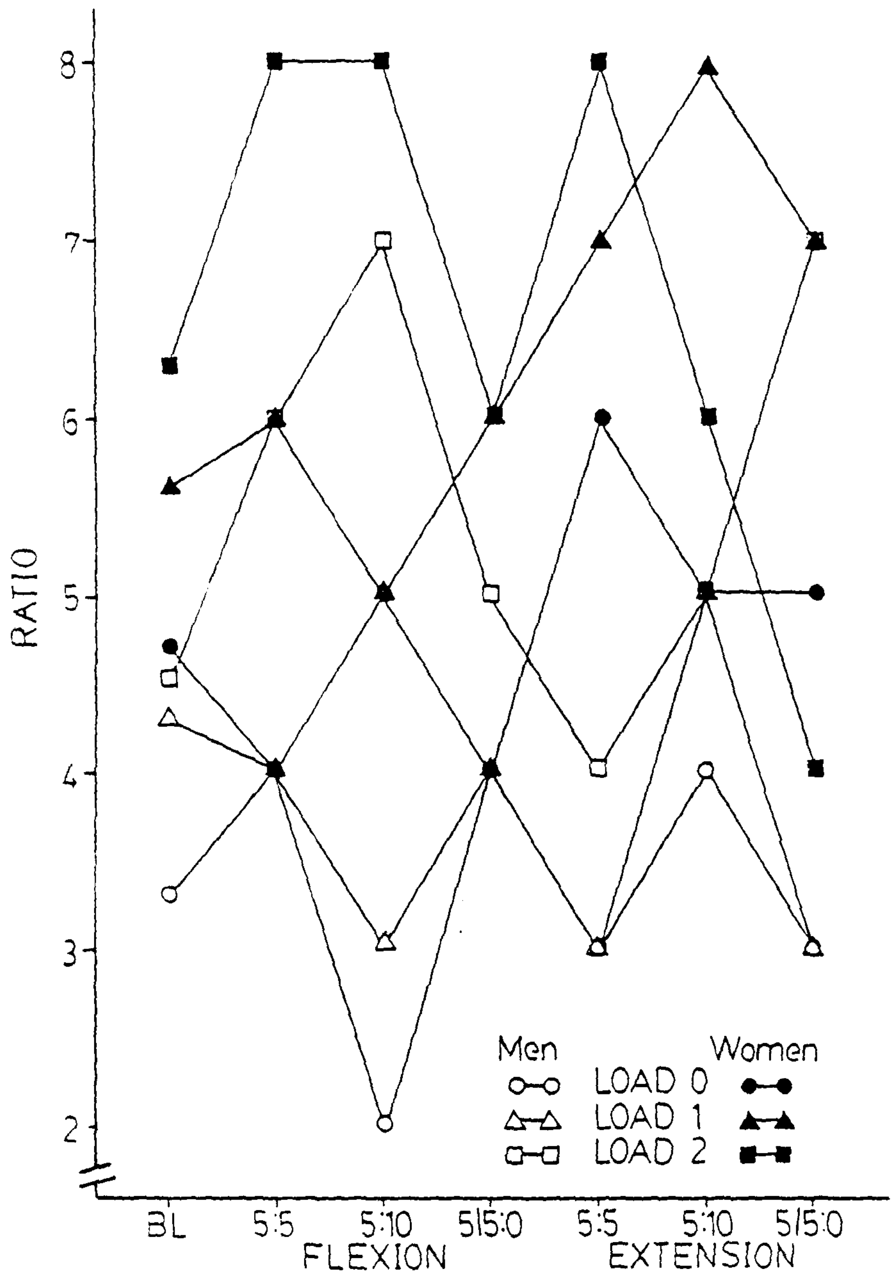

Fig. . Ratio Between Total Biceps EMG and Total Triceps EMG Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

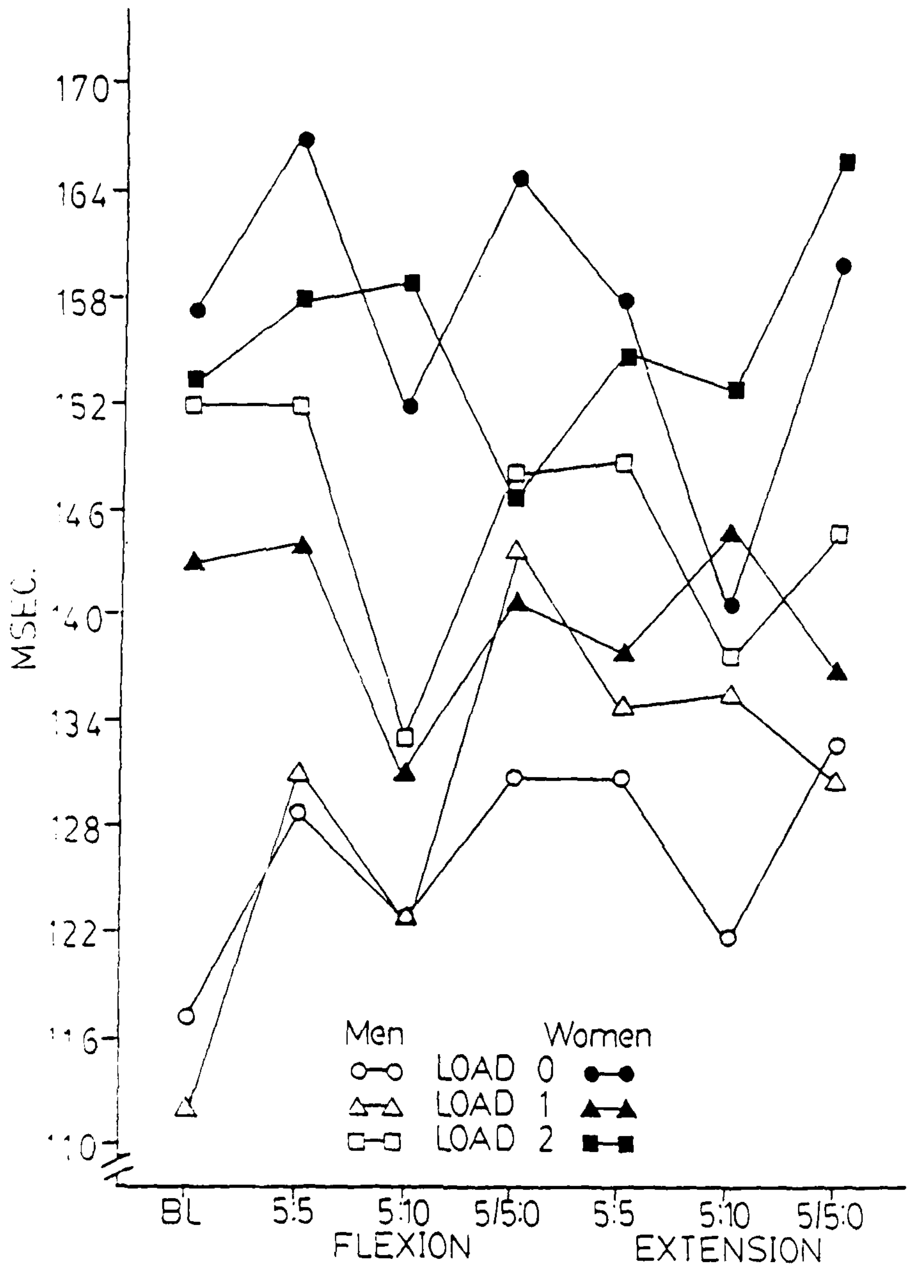

Fig. . Biceps Silent Period Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

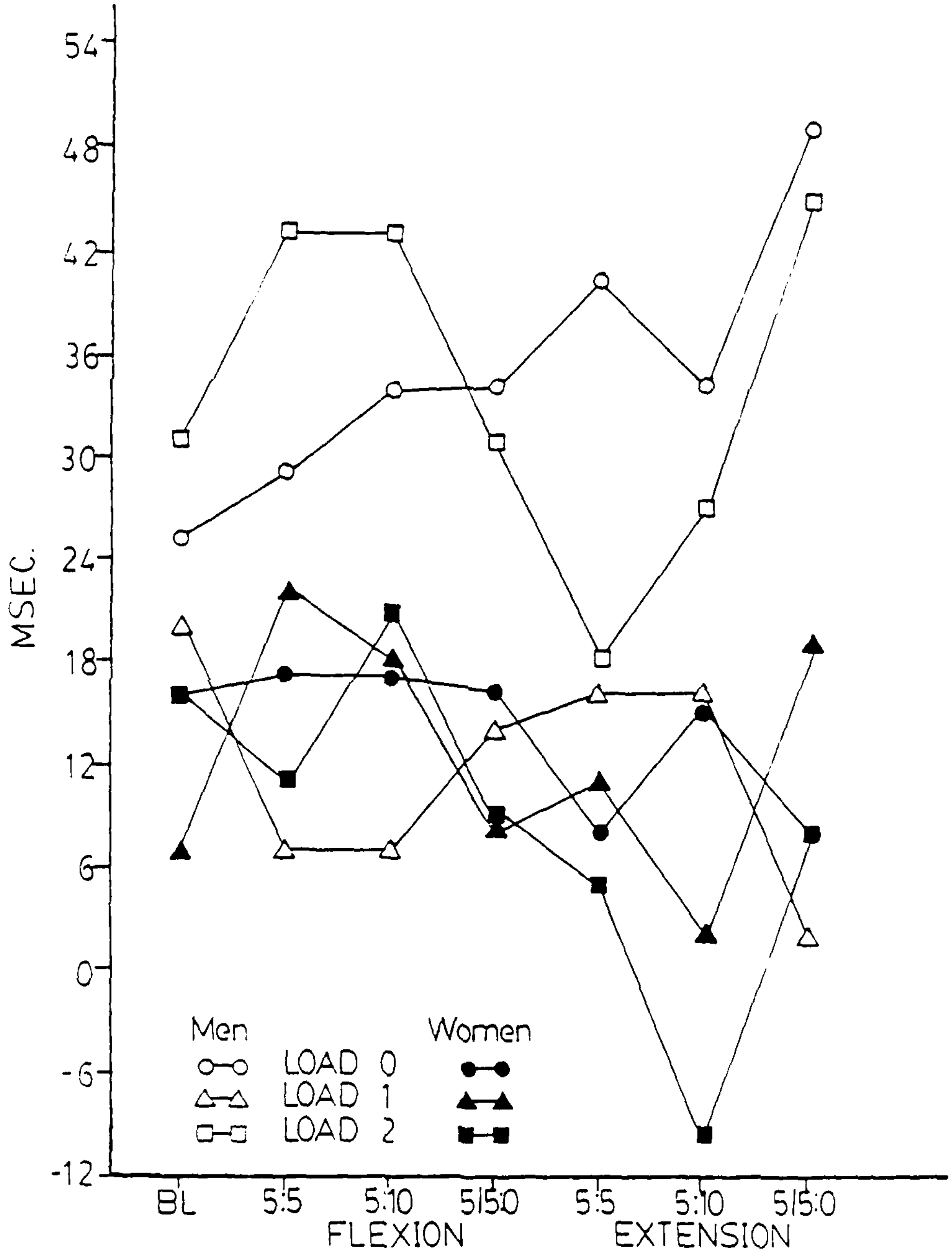

Fig. . First Biceps Burst to First Triceps Burst Latency Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Condition, N = 24.

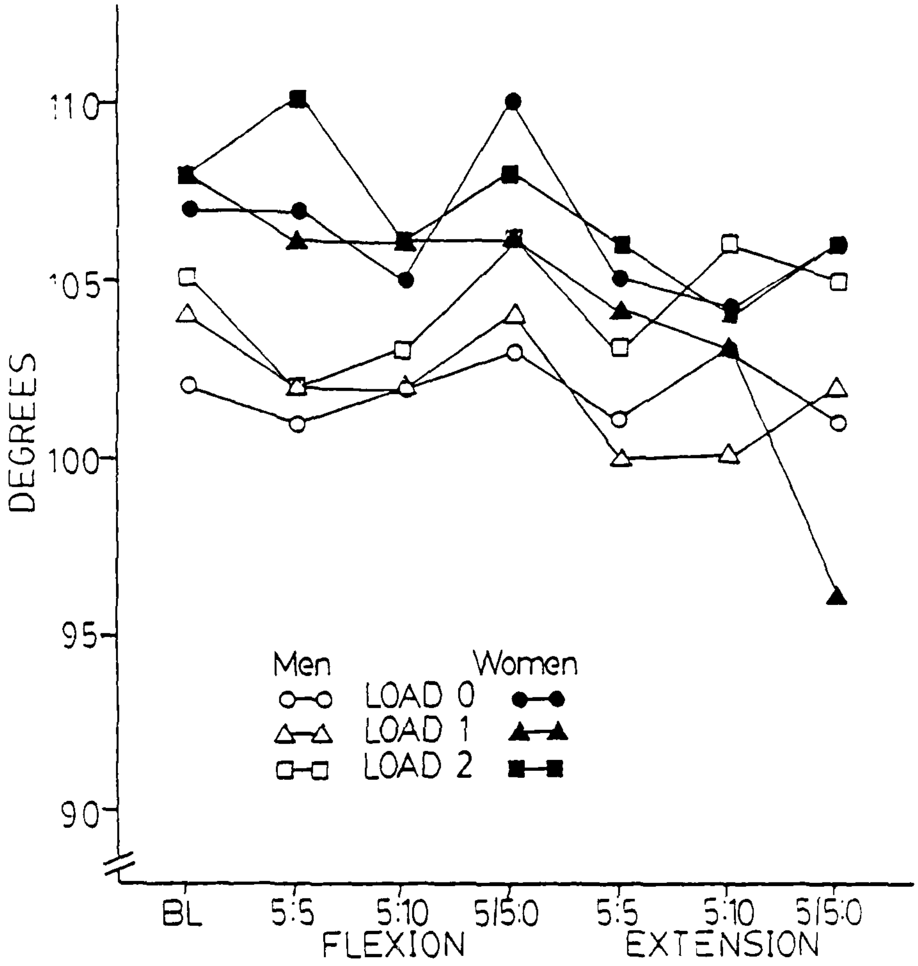

Fig. . Maximal Displacement Means for Baseline Pre-Exercise (BL) and after each Fatigue Regimen under all Load Conditions, N = 24.

APPENDIX F

Effects of Isometric Muscular Fatigue and the Tonic Vibratory Response on the Speed of Forearm Flexion Movement in Women

PROCEDURES

Selection of Subjects

Cohen's (11, p. 46-50) case 4 formula was utilized to determine a sample size with adequate sensitivity to detect a false null hypothesis. The case 4 formula requires the investigator to specify the level of significance of the test, the desired power, and the difference between baseline and post treatment means ("effect size") of a criterion measure considered to be an important difference.

The sample size determination was made using the criterion measure of movement time. Although the movement parameters of acceleration time and percent acceleration time could have been used to determine the size of the sample, both of these measures are intimately related to movement time. As movement time is the measure most representative of speed, and as changes in speed due to treatment were the main focus of this study, the criterion measure of movement time was deemed appropriate for use in the estimation of sample size. An effect size of 15 ms was selected, based on the results of previous studies (37, 56) and since this constituted a change of approximately 10% in the baseline criterion measure of movement time.

A power of .90 was selected, based on the post mortem sample size estimation of Wolcott (56). Wolcott (56) used a movement identical to that of the present study, and reported a reliability coefficient of .93, and standard deviation of 18.1 ms. This data was used in the calculation of Cohen's case 4 formula (11). Entering the appropriate power tables, at the .05 level of confidence, a sample size of 15 was determined.

The Department of Exercise Science policies for the use of human subjects in experimental research were followed and included a review of the thesis proposal by a departmental faculty committee. Fifteen women volunteers between the ages of 18 and 30 were used in this study. In accordance with the General Guidelines on the Rights and Welfare of Human Subjects approved by the Faculty Senate of the University of Massachusetts on May 11, 1971, all subjects were asked to read and sign an informed consent document. A copy of the informed consent document presented to subjects may be found in Appendix A. All subjects were medically cleared before participating in the research protocol.

All subjects were right handed, as determined by the hand used for writing. This limitation was imposed by the apparatus which was designed to test right handed people only. Female subjects were selected in order to contrast the results of this study with previous research on males (37, 56).

Selection of Parameters and Apparatus

Movement Selection.

The selection of forearm flexion as the movement for testing maximum speed was based on a review of the literature. The movement fulfills the qualities designated important by Wilkie (55) in the selection of an observable movement. The elbow is a geometrically simple joint, forearm flexion requires a limited number of muscles, with small insertions and origins, the movement has little effect on the rest of the body, and requires little skill. Person (46) has demonstrated that flexion of the forearm has a shorter agonist/antagonist coordination period which allowed subjects to reach a baseline measure of speed of forearm flexion movement quickly.

Due to the design of the equipment, the forearm flexion movement was performed in the sagittal plane, thus incorporating the force of gravity. In agreement with Wolcott (56), presence of the force of gravity was not considered to be a limitation of the study, as the force of gravity is a normal component in human motion. Half pronation of the hand was selected, as this position provided the greatest comfort and experimental control.

In the starting position for the speed of forearm flexion movement trials, the forearm was flexed to an angle of 160° with the upper arm. The upper arm rested on top of the testing apparatus, and formed a 90° angle with the subject's chest, which rested against the side of the testing apparatus. From the starting position, the subject was required to flex the forearm as quickly as possible, until the motion was stopped by contact with the shoulder, which was padded to prevent injury and hesitation.

A class A movement, one that is stopped by contact with another object or body part (6) was utilized for several reasons. It allowed the subject to consciously accelerate the forearm for a longer percentage of the total movement time than would have been possible if subjects were required to stop at a specific point in the motion. The class A forearm flexion movement also required less skill to perform than a class B movement, and subjects would have been able to reach stable baseline measures more rapidly. The time elapsed during the first 70° of movement was recorded as movement time, and is illustrated in Figure 1.

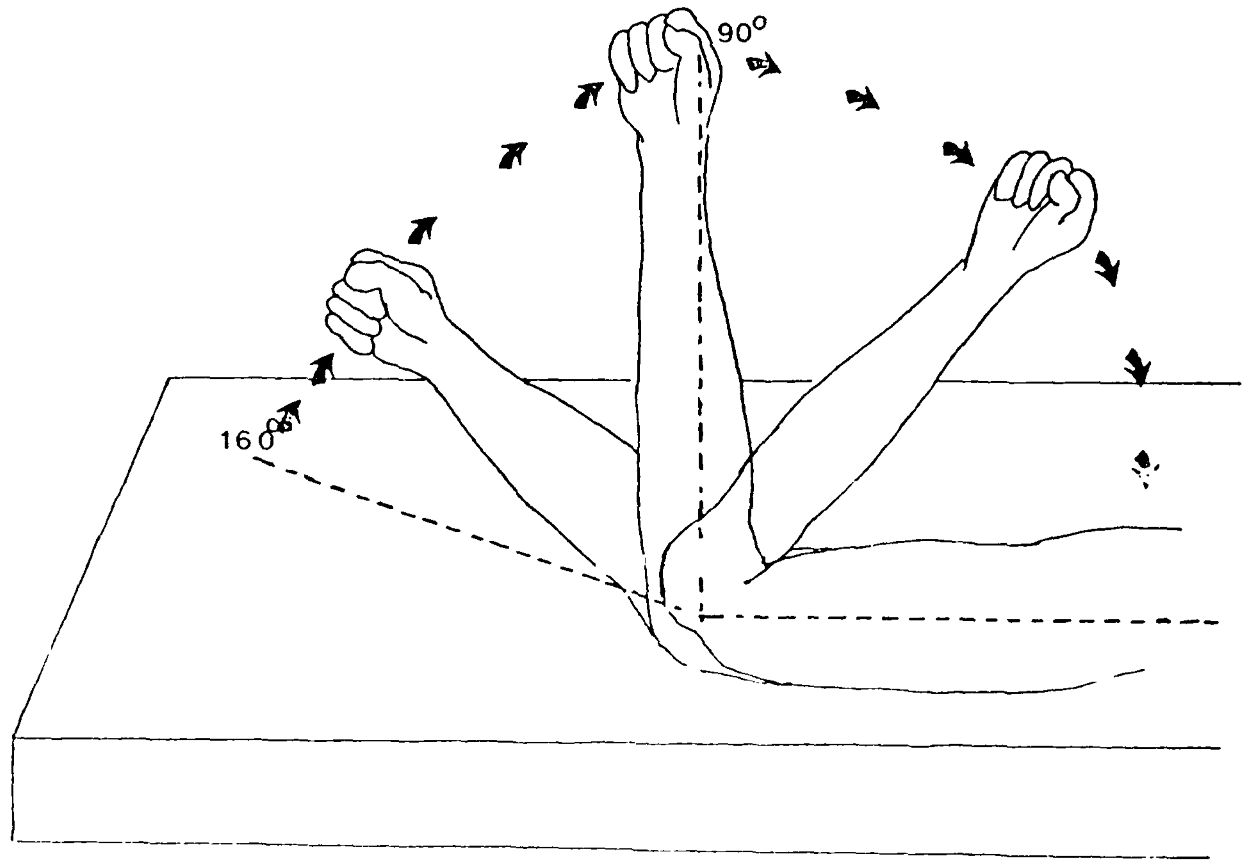

FIGURE 1. FOREARM FLEXION MOVEMENT

Movement apparatus.

The movement apparatus, as illustrated in Figure 1, was specifically designed and constructed to study the forearm flexion movement previously described. The apparatus was mounted on a table, which was secured to a supporting pillar. The level arm consisted of a light piece of pine wood, 2.0 cm across the top, and 3.5 cm in width, along a 50 cm length of the bar. The base of the bar was attached to an axle mounted in oil bearings. The side of the bar was slotted to allow the position of the wrist cuff to be adjusted to the length of the subjects' forearm. A wing nut assembly was used to position the wrist cuff to the left side of the bar. Two wooden blocks were attached to the testing table, with a microswitch mounted on each. The starting block was positioned so that the wooden bar was in contact with the microswitch of the starting block when the forearm of the subject was flexed to 160° with the upper arm. The terminating block was positioned at the subject's elbow, so that it was activated when the subject's arm passed through the 90° flexion position with the upper arm. The first microswitch opened when the bar was lifted, initiating a clock counter. The second microswitch opened the circuit, and stopped the clock, thus recording the time in ms of the first 70° of forearm flexion. The subject's shoulder was padded to allow

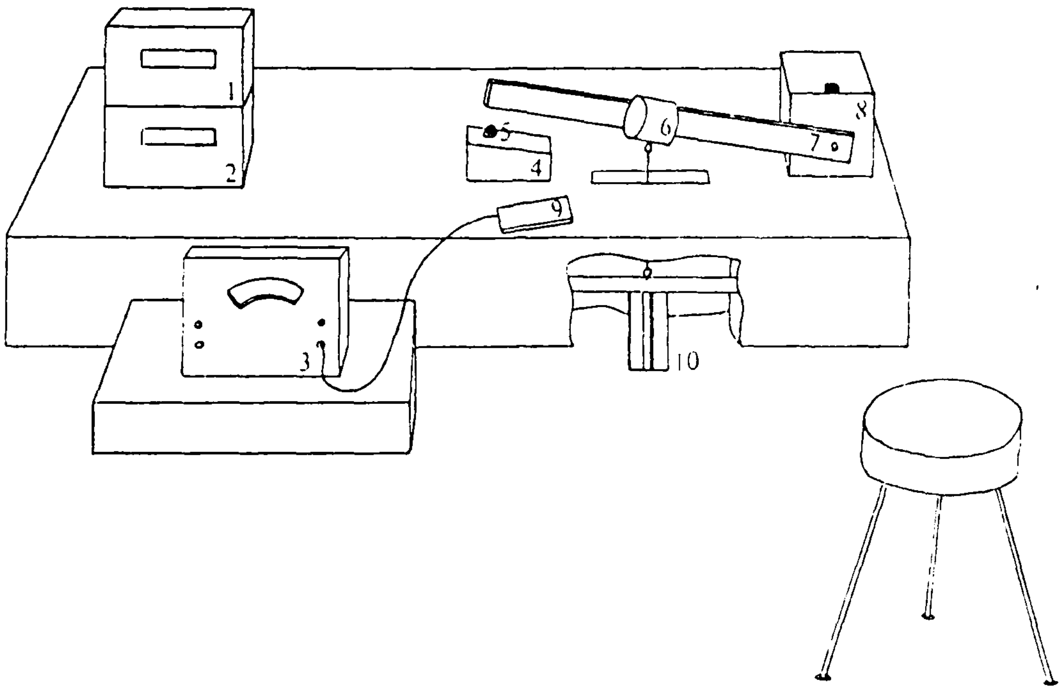

FIGURE 2. TESTING APPARATUS

Movement Time Clock
Acceleration Time Clock
Tonic Vibratory Response Unit
Starting Block
Microswitch 1
6 Wrist Cuff
7 Lever Arm
8 Potentiometer
9 Vibrator Head
10 Strain Gauge
11 Microswitch 2

the arm to pass through a full range of movement at maximum speed, without fear of injury. Figure 2 illustrates the testing appartus.

Speed of forearm flexion movement parameter.

Movement time, as recorded on the clock counter served as a measure of the speed of forearm flexion movement parameter. This consisted of the time required by the subject to move the forearm through the first 70° of flexion.

Acceleration time apparatus.

An instrument was designed to measure acceleration/ deceleration parameters of a forearm flexion movement. The acceleration time apparatus consisted of a potentiometer, electronic circuitry, and a clock counter. The potentiometer was contained in a metal box, and attached to the axle at the base of the wooden bar to which the subject's arm was attached. This apparatus measured limb displacement, as an electronic displacement signal which was then twice differentiated to determine the amount of time the arm was positively accelerating. The clock counter started with the initiation of movement, and stopped when the arm was no longer positively accelerating. The time displayed on the clock was the time to zero acceleration.

Acceleration time parameter.

A clock started upon initial acceleration from the resting position, and stopped when the arm was no longer positively accelerating. This acceleration/deceleration point is indicative of the agonist/antagonist coordination of the movement, as the timing of the contraction of the triceps determined the acceleration/deceleration point.

Percent acceleration time parameter.

Percent acceleration time was defined as the percent of total movement time the arm spent positively accelerating. This was measured as time to zero acceleration and then converted to a percentage of the total forearm flexion movement time.

Maximum isometric flexion and extension strength, and isometric flexion and extension fatiguing exercise apparatus

Fatigue of forearm flexors and extensors was induced isometrically due to the ease of measurement and control. In order to induce fatigue of the forearm flexor, the arm was placed in the starting position, and attached to a strain gauge mounted below the surface of the table to a wooden board with a slit down the center. The slotted board allowed the position of the strain gauge to be adjusted to the length of the subject's arm. 'S' hooks and chain link were used to attach the wrist cuff to the strain gauge. Force exerted by the subject on the strain gauge was recorded in kilograms on a Beckman Type R dynograph. The forearm was flexed to an angle of 90° during maximum isometric forearm extension strength trials as this position coincided with the end of recorded movement time, and was the point of greatest mechanical advantage. A wooden structure was placed in front of the subject to brace the strain gauge during maximum isometric extension strength trials. The strain gauge was attached to the wrist cuff by means of an 'S' hook. An illustration of the maximum isometric extension strength testing apparatus can be seen in Figure 3.

Strength testing involved two types of maximum voluntary contractions (MVC): a slow MVC, and a fast MVC. A slow MVC consisted of a build-up to maximum contraction over a period of five seconds. The fast MVC was a contraction with as much force and speed as the subject was able to attain, and an equally rapid release of the contraction.

Maximum isometric flexion and extension strength parameters, and isometric flexion and extension fatiguing exercise regimen

The forearm was placed in the speed of forearm flexion movement starting position to test for maximum isometric strength of the forearm flexors. The subject produced three

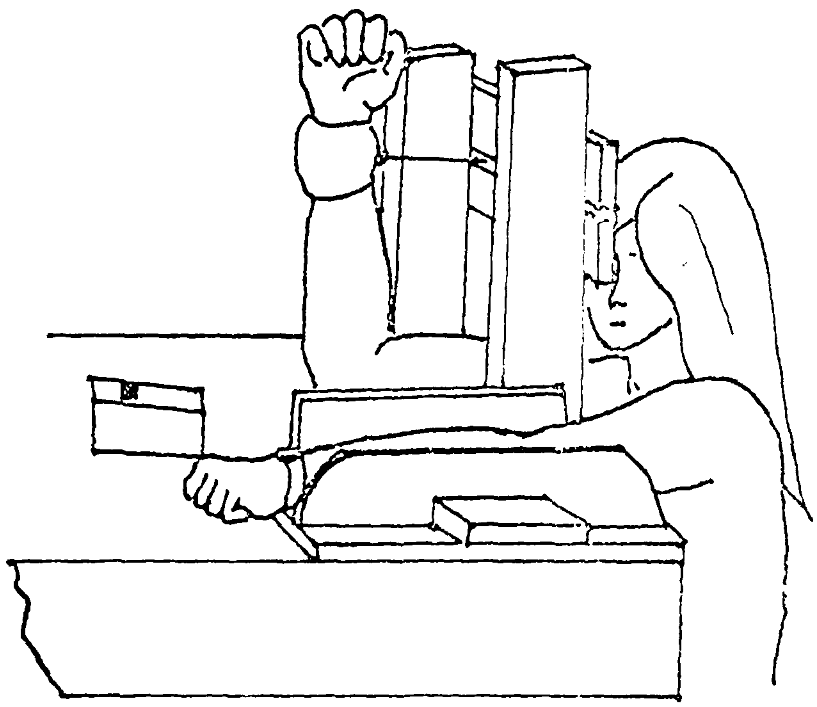

FIGURE 3. MAXIMUM ISOMETRIC EXTENSION STRENGTH
TESTING POSITION

maximum isometric contractions of the forearm flexors, and an average of the three trials was recorded as the baseline measure of strength in kilograms. The three maximum isometric flexion strength trials included two slow maximum voluntary contractions, with one fast maximum voluntary contraction between the two slow maximum voluntary contractions. Subjects received one minute rest between each contraction, and five minutes rest before maximum isometric extension strength testing was performed. The isometric flexion fatiguing exercise regimen was performed in the same position as the maximum isometric flexion strength testing, and consisted of a series of 30 slow maximum voluntary contractions of the forearm flexors.

In order to test the isometric strength of the forearm extensors, the forearm was placed at an angle of 90° with the upper arm. A wooden structure was then placed between the shoulder and the forearm of the subject. The subject pushed away to exert force on the strain gauge, which was recorded as the maximum voluntary isometric forearm extension strength. As with maximum voluntary isometric flexion strength testing, subjects performed two sustained five second maximum voluntary isometric contractions of the triceps with a fast maximum voluntary isometric contraction between two slow maximum voluntary isometric contractions.

The five second maximum voluntary isometric extension contraction was repeated 30 times in an attempt to induce fatigue of the triceps muscle. A 90° position was used because it coincided with the ending of the recorded movement time.

Tonic vibratory response apparatus.

A Zenitar TVR unit with a cylindrical rotating head was used to evoke the tonic vibratory response. This unit had an adjustable frequency range of 10-130 Hz, and a constant amplitude of 2 mm.

Tonic vibratory response.

Although EMG activity was not recorded in this study, there is reason to believe that all subjects experienced a tonic vibratory reponse (TVR). Eklund and Hagbarth (19) were able to elicit a TVR in all subjects, in all muscles during a period of 100 seconds of vibration at 160 Hz, as were Johnston, et al. (32) with vibration of 120 Hz for 20-60 second periods.

The cylindrical vibrator head was placed transversely across the muscle belly in order to vibrate the largest amount of muscle mass. Although vibration of the muscle tendon has been shown to produce a greater tonic vibratory response (TVR) (13, 15, 19) the purpose of this study was to examine the effects of the TVR on the muscle spindle, not the Golgi tendon organ. Vibration at the elbow also ran the risk of transferring to the opposing muscle, thus confounding results.

The frequency of vibration was between 100-110 Hz (19). The exact frequency was determined by the subjects' estimation of the frequency having the greatest effect on perceived muscle tension (24).

The vibrator head was hand held over the biceps, or under the triceps. The force of gravity was the only pressure acting on the vibrator as it rested on the biceps brachii. The partial weight of the upper arm resting against the vibrator determined the amplitude of vibration when the triceps was vibrated. Goldfinger and Schoon (22) found the amplitude of vibration to have no effect upon the resultant TVR, at a frequency of 100 Hz and amplitudes between 20-40 mm.

Testing Procedures

Initial testing procedures.

At the initial testing session, subjects were asked to sign an informed consent document as required by the University of Massachusetts, Amherst. Then the age, height, and weight of each subject was recorded. A demonstration and explanation of the testing apparatus, followed by an opportunity to ask questions preceded the actual testing. Subjects were then placed in the initial testing position. The stool was adjusted so the subject's upper arm was at a 90° angle with her trunk. The elbow was placed in line with the axle, and attached to the lever arm by means of the wrist cuff. The padded chest rest was placed against the subject's chest and tightened, and the shoulder pad taped to her upper arm.

Maximum isometric flexion and extension strength testing.

Maximum isometric forearm flexion and extension strength was determined by attaching the wrist cuff to a strain gauge as previously described. Subjects performed two slow maximum voluntary contractions, (slow MVC), with one fast maximum voluntary contraction (fast MVC) interspersed between the two slow. A set of three maximum voluntary contractions of the forearm flexors and extensors were performed at the beginning of each testing session. The paper speed of the Beckman Dynograph was set at 5 mm/sec. during slow MVC trials, and 250 mm/sec. during fast MVC trials.

The subject responded to a recorded signal "ready go", by building up to a maximum contraction over a five second period. After five seconds, the signal "ready relax" was given. During administration of fast MVC, the only pre-recorded instruction was "ready, GO", which subjects responded to by contracting with maximum speed and strength.

Speed testing.

In the starting position for speed of forearm flexion movement testing, the forearm was at 160° of flexion with the upper arm in a horizontal position. In response to recorded instruction "ready go", the subject flexed her forearm as quickly as possible through the entire range of motion, making no attempt to arrest the motion. The clock counter readouts were recorded, and reset by the experimenter as subject resumed starting position.

As the first two days of testing were used to establish baseline scores for movement time, acceleration time, and maximum isometric flexion and extension strength measures, no treatment was applied. Subjects performed 50 speed of forearm flexion movements on each of the two baseline days. These were performed in five blocks of ten trials with 20 seconds separating each trial, and three minutes between each block of ten trials.

On treatment days, the speed of forearm flexion movement baseline was re-established by performing one block of ten speed of forearm flexion movement trials. The treatment was applied and further speed of forearm flexion movement trials followed.

Isometric fatiguing exercise treatment days.

The isometric fatiguing exercise treatment days began with baseline maximum isometric flexion and extension strength testing followed by a five minute test, and one block of ten speed of forearm flexion movement trials. Following a three minute rest, subjects performed 30 slow maximum voluntary contractions of five seconds duration with 10 seconds rest between each trial. The strain gauge was removed, and subjects immediately began a set of five speed of forearm flexion movement trials. Following the five speed of forearm flexion movement trials, subjects immediately performed one slow maximum voluntary contraction of both the forearm flexors and extensors, as a measure of post treatment isometric strength.

Tonic vibratory response treatment days.

The tonic vibratory response treatment (TVR) days began with the recording of baseline measures of maximum isometric flexion and extension strength, and speed of forearm flexion movement. The TVR treatment consisted of 100 seconds of vibration at a frequency of 100-110 Hz, immediately followed by five speed of forearm flexion movement trials. The sequence of 100 seconds of vibration, five speed of forearm flexion movement trials was repeated four times, with 20 seconds rest between each speed of forearm flexion movement trial. Maximum isometric strength measures ended the session. Subjects performed one maximum voluntary contraction of the forearm flexors, and one of the forearm extensors, with no intermediate rest period, to determine post treatment maximum isometric strength.

Balancing of treatments.

Tonic vibratory response (TVR) and isometric fatiguing exercise treatments, as well as maximum isometric flexion and extension strength measures (FS, and ES), were balanced over subjects and across days. The particular order of treatment was determined by order of attendance to the laboratory for testing. For example, the first subject received the TVR treatments before the isometric fatiguing exercise treatments, and the second subject received the isometric fatiguing exercise treatments before the TVR treatments. In this same manner, the first subject performed the baseline maximum isometric strength testing in the order FS, then ES, and the post treatment maximum isometric strength testing in the order ES, then FS, while the second subject performed these measures in the reverse order. The order of maximum isometric strength measures determined the order of each set of treatments. For example, subject one began days 1, 3, and 5 with FS, then ES baseline measures, and ended with ES, then FS post treatment measures. On days 3 and 5, subject one received extension TVR and isometric extension fatiguing exercise treatments. This order ensured that the post treatment maximum isometric strength measure of the treated muscle group was taken immediately after the treatment-speed of forearm flexion movement trials sequence. The second post treatment maximum isometric strength measure was always that of the untreated muscle group. A clearer picture of the order of testing may be gleaned from Table 1.

TABLE 1

MEASUREMENT SCHEDULE

PRACTICE DAYS	ISOMETRIC FATIGUING EXERCISE TREATMENT DAYS	TONIC VIBRATORY RESPONSE TREATMENT DAYS
BASELINE MEASURES:	BASELINE MEASURES:	BASELINE MEASURES:
MAXIMUM ISOMETRIC STRENGTH OF FOREARM FLEXORS OR EXTENSORS	MAXIMUM ISOMETRIC STRENGTH OF FOREARM FLEXORS OR EXTENSORS	MAXIMUM ISOMETRIC STRENGTH OF FOREARM FLEXORS OR EXTENSORS
1 S-MVC*, 1 MIN REST 1 F-MVC**, 1 MIN REST 1 S-MVC, 5 MIN REST	1 S-MVC, 1 MIN REST 1 F-MVC, 1 MIN REST 1 S-MVC, 5 MIN REST	1 S-MVC, 1 MIN REST 1 F-MVC, 1 MIN REST 1 S-MVC, 5 MIN REST
Repeat Series of 3 MVC's on Opposing Muscle Group	Repeat Series of 3 MVC's on Opposing Muscle Group	Repeat Series of 3 MVC's on Opposing Muscle Group
	10 MSFFM BASELINE TRIALS 20 SEC REST BETWEEN TRIALS	10 MSFFM BASELINE TRIALS 20 SEC REST BETWEEN TRIALS
	3 MIN REST	3 MIN REST
PRACTICE OF MSFFM***	ISOMETRIC FATIGUING EXERCISE TREATMENT OF THE FOREARM FLEXORS OR EXTENSORS	TVR TREATMENT OF THE FOREARM FLEXORS OR EXTENSORS
5 BLOCKS: 10 MSFFM TRIALS/BLOCK 50 TRIALS TOTAL 20 SEC REST BETWEEN TRIALS 3 MIN REST BETWEEN BLOCKS	30 S-MVC's 10 SEC REST BETWEEN S-MVC's 5 MSFFM TRIALS 20 SEC REST BETWEEN TRIALS	4 BLOCKS: 100 SEC VIBRATION 5 MSFFM TRIALS 20 SEC REST BETWEEN TRIALS 20 MSFFM TRIALS TOTAL
POST PRACTICE MAXIMUM ISOMETRIC STRENGTH MEASURES FOREARM FLEXORS OR EXTENSORS	POST FATIGUE MAXIMUM ISOMETRIC STRENGTH MEASURES FOREARM FLEXORS OR EXTENSORS	POST TVR TREATMENT MAXIMUM ISOMETRIC STRENGTH MEASURES FOREARM FLEXORS OR EXTENSORS
1 S-MVC OF TREATED MUSCLE GROUP 1 S-MVC OF UNTREATED MUSCLE GROUP	1 S-MVC OF TREATED MUSCLE GROUP 1 S-MVC OF UNTREATED MUSCLE GROUP	1 S-MVC OF TREATED MUSCLE GROUP 1 S-MVC OF UNTREATED MUSCLE GROUP

*SLOW MAXIMUM VOLUNTARY CONTRACTION
**FAST MAXIMUM VOLUNTARY CONTRACTION
***MAXIMUM SPEED FOREARM FLEXION MOVEMENT

Statistical Treatment of the Data

Reliability of baseline measures.

In order to determine the differences in a criterion measure that are due to a treatment, the reliability of the measure must be established. Baseline measures of movement time, acceleration time, percent acceleration time, and maximum isometric flexion and extension strength were established on practice days one and two for all subjects. This baseline was continuously monitored at the beginning of each session for each of the criterion measures.

The intraclass reliability coefficient was used to determine the consistency of each of the baseline measures recorded over the six day testing period. A low trial to trial variation of baseline measures was necessary to make comparisons between pre and post treatment measures of movement time, acceleration time, percent acceleration time and maximum isometric flexion and extension strength.

The stability of the baseline criterion measures was tested utilizing a series of repeated measures analysis of variance tests (REANOVAs). It was expected that the day to day variation in movement time, acceleration time, and percent acceleration time would decrease after the second

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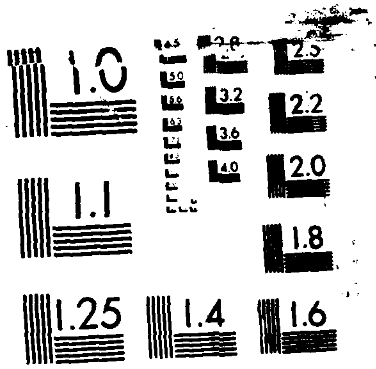

MICROCOPY RESOLUTION TEST CHART

day of testing, as the main purpose of the first two days was to establish stable baseline scores for these measures. It was possible that the maximum isometric flexion and extension strength baseline measures would continue to change with practice.

<u>Effect of speed of forearm flexion movement trials on maximum isometric strength.</u>

Maximum isometric flexion and extension strength measures were recorded before and after each treatment-speed of forearm flexion movement trials sequence. In order to determine the cause of any change in the pre to post treatment maximum isometric strength measures, the effect of the speed of forearm flexion movement trials alone had to be ascertained. This was accomplished using a repeated measures analysis of variance design (REANOVA) to determine the significance of any difference found in the maximum isometric flexion and extension strength before and after 50 speed of forearm flexion movement trials. If the pre and post maximum isometric flexion and extension strength measures did not differ significantly before and after 50 speed of forearm flexion movement trials, then any significant differences in pre to post treatment maximum isometric strength measures on treatment days would safely be attributed to the treatment rather than to the speed of forearm flexion movement trials.

Pearson product-moment correlational analysis.

A Pearson product-moment correlational analysis was conducted to compare movement time, acceleration time, percent acceleration time, maximum isometric flexion and extension strength, height, weight, and age of the subjects to every other variable to determine the existence of common variance.

Fatigue and movement parameters.

A series of 30 maximum voluntary contractions were performed in an attempt to effect a change in the movement parameters of the speed of forearm flexion movement. Before any conclusions can be drawn regarding the results of the isometric fatiguing exercise regimens, it must first be established that a decrement in maximum isometric strength has actually occurred. A series of repeated measures analysis of variance (REANOVAs) were performed for maximum isometric flexion and extension strength scores prior to, during, and after the isometric fatiguing exercise regimens, in order to test for a strength decrement. Once a significant strength decrement, or lack of same, had been established, a series of REANOVAs were employed to determine the significance of any observed differences in the criterion measures of movement time, acceleration time, percent acceleration time and maximum isometric strength of the non-fatigued muscle group.

Tonic vibratory response and movement parameters.

An attempt was made to evoke a tonic vibratory response (TVR) four times in each muscle group on two days, one day of vibration of the forearm flexors, and one day of vibration of the forearm extensors. To test the significance of differences in movement time, acceleration time, percent acceleration time, and maximum isometric flexion and extension strength following TVR treatment, two sets of repeated measures analysis of variance tests (REANOVAs) were performed. One REANOVA was performed to test the significance of the differences found in the means of the four blocks of five speed of forearm flexion movement trials. A second set of REANOVAs was performed to test for trial to trial differences, as the TVR is believed to be a time locked phenomenon, lasting approximately 30 seconds after the removal of vibration.

ANALYSIS OF THE DATA

Introduction

The results of the analysis of the data are presented and discussed. Physical characteristics of the subjects, and a post-mortem power analysis are presented initially. The reliability of the data is established next. Then the effects of practice on the criterion measures, and the interrelationships of the baseline measures are reported. This is followed by a presentation of the effects of speed of forearm flexion movement trials on maximum isometric strength. The next two sections delineate the effects of isometric fatiguing exercise, and tonic vibratory response treatments on the recorded movement parameters, and on maximum isometric strength. A discussion of the results follows their presentation.

Results

Physical characteristics of the subjects.

The fifteen women who volunteered to participate in this study were medically cleared to participate, and considered to be in good health. None of the subjects were

TABLE 2

MEAN, STANDARD DEVIATION, AND RANGE OF THE AGE, HEIGHT AND WEIGHT OF THE SUBJECT SAMPLE

	Mean	Standard Deviation	Range
ɩge (years)	22.3	2.3	18 - 26
ɩeight (cm)	164.3	4.8	157.5-172.7
ɩeight (kg)	60.5	10.2	50.4- 84.4

participating in a training program at the time of testing. The mean, standard deviation, and range of the age, height, and weight of the subject sample are presented in Table 2.

Post mortem analysis of sample size estimate.

The initial power analysis, based upon an effect size of 15 ms, a reliability coefficient of .93, and a standard deviation of 18.1 ms yielded a power of .90 for a sample size of 15, at the .05 level of confidence. This estimate was based on data, reported by Wolcott (56), for a class A forearm flexion movement in an unloaded condition. The post mortem power analysis, which was based on a movement time effect size of 15 ms, a reliability coefficient of .90, and a standard deviation of 14.3, resulted in a power of .96 at the .05 level of confidence for a sample size of 15. The calculations of these power analyses are presented in Appendix B.

With the precision available in the present study, any change in movement time of 10 ms would be declared statistically significant. It was originally stipulated that a change in movement time, due to treatment conditions, of 15 ms, or greater, had practical significance. If such a difference occurred, the precision available in the experimental design should be such that an observed change of practical significance should be statistically significant. A post mortem analysis of the baseline measure of movement time revealed adequate precision to detect a 10 ms change in movement time as statistically significant. The precision allowed by the experimental design was greater than the precision demanded by the effect size.

Reliability of baseline measures.

In order to detect significant changes in the criterion measures, it was necessary to establish the reliability of the baseline measures. Baseline measures of movement time (MT), acceleration time (ACT), percent acceleration time (PAT), and maximum isometric flexion (FS) and extension strength (ES) were secured on practice days one and two, and monitored at the beginning of each treatment session.

Intraclass reliability coefficients were secured for each of the five baseline measures to illustrate the consistency of these measures. All measures proved to be highly consistent, as the reliability coefficients for all measurements ranged between .78 and .94. MT and ACT yielded lower error variance over blocks than over days, while PAT, FS and ES demonstrated small and approximately equal error variance over days and blocks. The means, standard deviations, variance estimates and reliability coefficients for these measurements are presented in Table 3.

TABLE 3

ERROR VARIANCE COMPONENTS, INTRACLASS RELIABILITY COEFFICIENT, MEAN AND STANDARD DEVIATION FOR BASELINE MEASURES OF MOVEMENT TIME, ACCELERATION TIME, PERCENT ACCELERATION TIME, AND MAXIMUM ISOMETRIC FLEXION AND EXTENSION STRENGTH OVER SIX SESSIONS

Measure	6^2 trials	6^2 days	6^2 true score	RI*	Mean	SD
Movement Time (ms)	69.5	87.8	183.9	.90	147.1	17.25
Acceleration Time (ms)	10.9	16.7	13.4	.78	89.8	5.62
Percent Acceleration Time (%)	17.5	17.6	23.3	.84	61.9	6.92
Maximum Isometric Flexion Strength (kg)	0.8	1.9	3.8	.92	9.8	2.00
Maximum Isometric Extension Strength (kg)	1.7	1.6	5.5	.94	10.4	2.40

* Intraclass Reliability Coefficient

Stability of baseline measures.

The stability of the baseline means of movement time (MT), acceleration time (ACT), percent acceleration time (PAT), and maximum isometric flexion (FS) and extension strength (ES) over six days was assessed through a series of two way analyses of variance. No significant differences were found over six days of baseline trials in MT, ACT, PAT, or FS. ES did show a significant increase ($p < .05$), indicating that subjects became stronger over testing days. The means of baseline MT and ACT scores varied within a 5 and 3 ms range respectively, while PAT means remained within three percentage units over treatment days four through six. Mean FS and ES varied 1.1 kg and 1.8 kg respectively over the testing period. The six day means, standard deviations, and F-ratios are presented in Table 4 for MT, ACT, PAT, FS and ES, and graphically represented in Figures 4, 5 and 6.

Two types of isometric contractions were used to determine the baseline maximum isometric strength, two slow maximum isometric contractions, and one fast maximum isometric contraction. The three score baseline means ($X_{1,2,3}$) are reported in Table 4 and represent the pre-treatment maximum isometric strength measures. A valid argument could be made in favor of computing the baseline strength scores as the mean of the two slow contractions,

TABLE 4

DAILY MEANS AND STANDARD DEVIATIONS DAYS 1 THROUGH 6 AND F-RATIO OF THE DAYS EFFECT ON THE BASELINE MEANS OF MOVEMENT TIME, ACCELERATION TIME, PERCENT ACCELERATION TIME, AND MAXIMUM ISOMETRIC FLEXION AND EXTENSION STRENGTH

Measure	Day 1 Mean SD	Day 2 Mean SD	Day 3 Mean SD	Day 4 Mean SD	Day 5 Mean SD	Day 6 Mean SD	F-Ratio
Movement Time (ms)	151.0	150.4	144.4	144.8	143.3	148.7	1.41
	18.5	20.2	19.1	16.8	12.4	16.5	
Acceleration Time	89.5	91.8	89.6	90.1	89.1	88.9	0.72
	10.3	4.9	5.3	4.1	4.1	5.0	
Percent Acceleration Time (%)	60.3	62.2	63.0	63.0	62.6	60.5	0.86
	9.0	7.6	7.0	7.9	4.3	6.1	
Maximum Isometric Flexion Strength (kg)	9.31	9.54	9.68	10.36	10.10	10.03	1.86
	1.87	2.18	2.67	2.17	2.74	2.67	
Maximum Isometric Extension Strength	9.64	10.43	10.63	10.32	10.13	11.19	2.51*
	2.83	2.76	2.97	3.05	2.49	3.22	

* $p < .05$

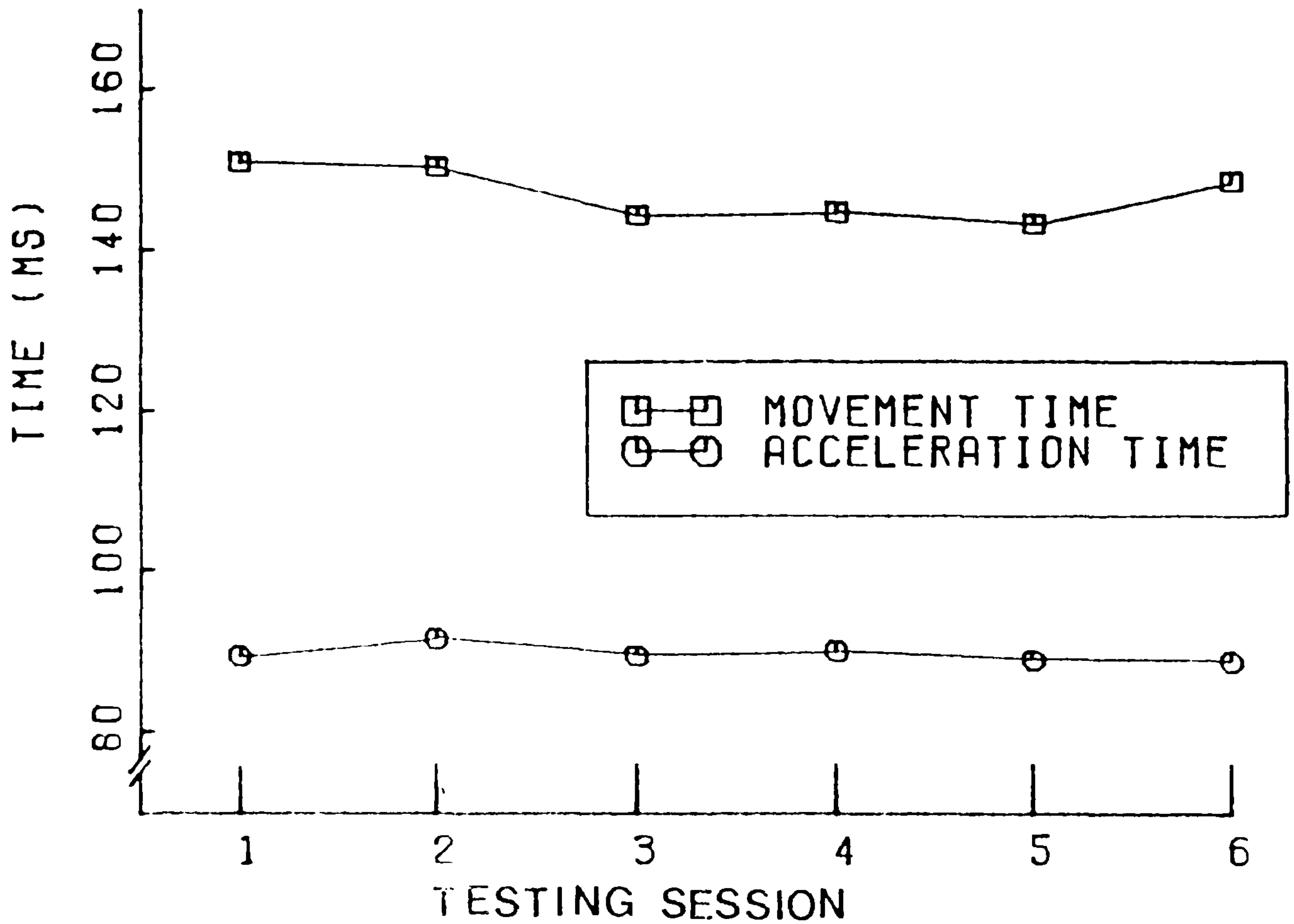

Figure 1. Baseline Means for Movement Time and Acceleration Time

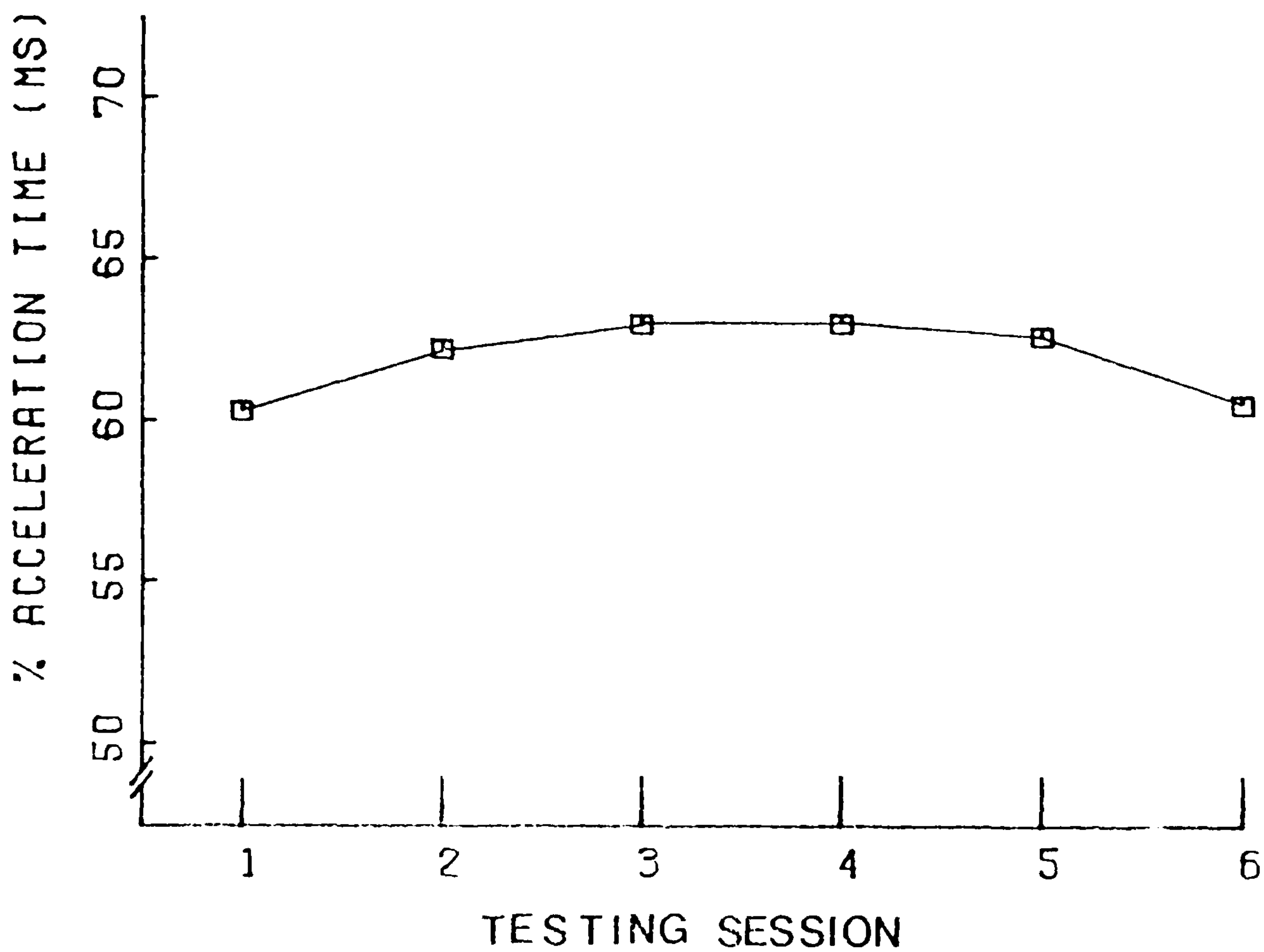

Figure 5. Baseline Means for Percent Acceleration Time, Days 1-6.

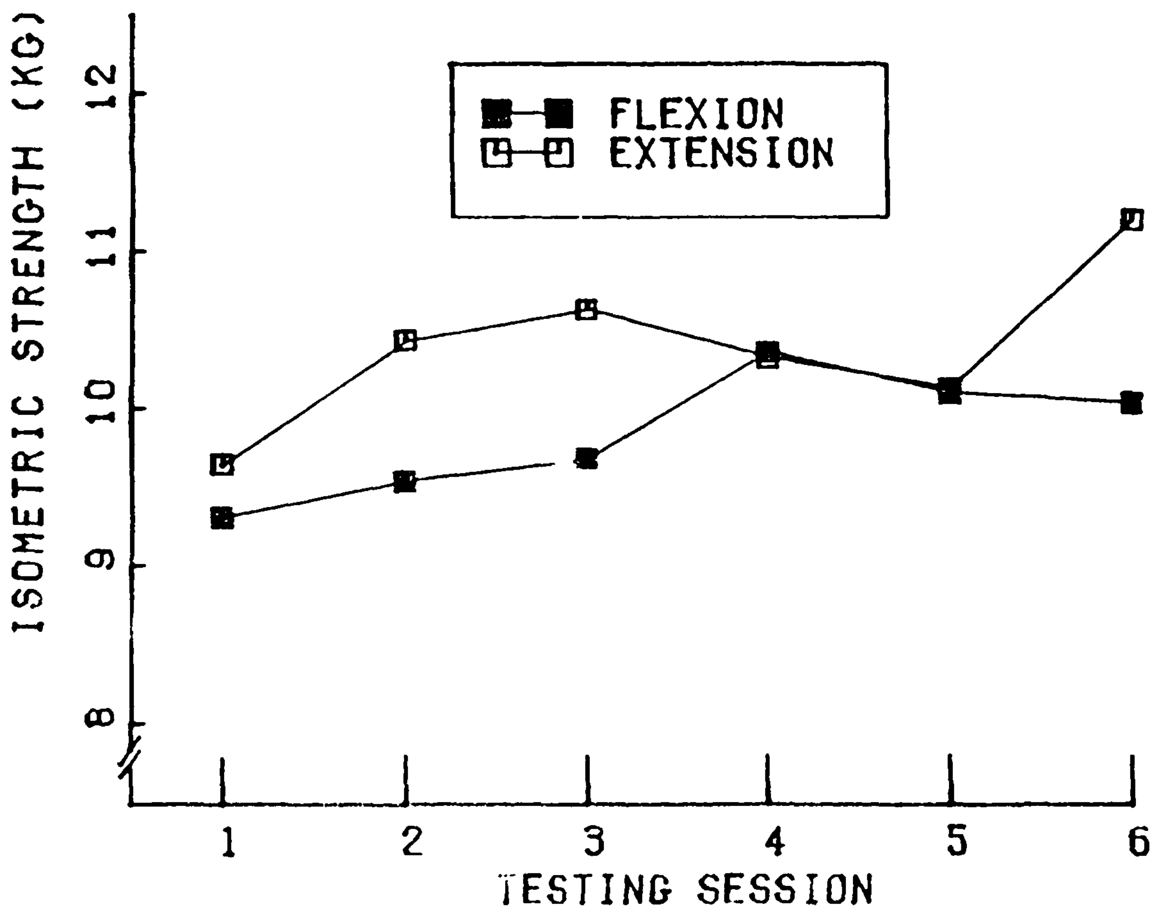

Figure 6. Baseline Means for Maximum Isometric Flexion and Extension Strength, Days 1-6

averaged, and the fast contraction ($X_{1\ 2\ ,3}$). The six day baseline mean of maximum isometric flexion strength was 0.08 kg or 0.8% greater and 0.20 kg or 1.9% greater for maximum isometric extension strength using the computation method $X_{1\ 2\ ,3}$ instead of $X_{1,2,3}$. These scores are presented in Tables 5 and 6. The three trial mean ($X_{1,2\ ,3}$) was utilized to compute the baseline measure of maximum isometric strength. Since the post-treatment strength measure consisted of only one slow contraction, and in view of the small differences involved, the added weight of the two slow contractions over one fast contraction seems justified.

Practice effects

The movement parameters of movement time (MT), acceleration time (ACT), and percent acceleration time (PAT) were examined for practice effects utilizing a repeated measures analysis of variance design (REANOVA). A REANOVA based on the six daily means of baseline measures yielded no significant differences in the movement parameters. As previous studies of forearm flexion movement were able to demonstrate significant increases in speed and PAT (37, 56), it was somewhat surprising to find no significant improvement over six days.

TABLE 5

BASELINE MAXIMUM ISOMETRIC FLEXION STRENGTH DAILY MEANS OF EACH OF TWO SLOW AND ONE FAST MAXIMUM VOLUNTARY CONTRACTIONS, DAYS 1-6

Day	Slow 1	Slow 2	Fast	$\bar{X}_{S1,S2,F}$
1	9.16	9.01	9.76	9.31
2	9.14	9.57	9.92	9.54
3	9.68	9.41	9.95	9.68
4	10.17	10.06	10.86	10.36
5	9.96	10.07	10.26	10.10
6	10.16	9.75	10.17	10.03
Six Day $\bar{X}$	9.71	9.65	10.15	9.84
Six Day $\bar{X}_{S1\ S2,F}$			9.92	
Six Day $\bar{X}_{S1,S2,F}$			9.84	
Difference			0.08 kg	
Percent Difference			0.81 %	

TABLE 6

BASELINE MAXIMUM ISOMETRIC EXTENSION STRENGTH DAILY MEANS OF EACH OF TWO SLOW AND ONE FAST MAXIMUM VOLUNTARY CONTRACTIONS, DAYS 1-6

Day	Slow 1	Slow 2	Fast	$\overline{X}_{S1,S2,F}$
1	9.11	9.68	10.13	9.64
2	9.72	10.16	11.41	10.43
3	10.08	10.48	11.33	10.63
4	9.82	10.10	11.06	10.32
5	9.45	9.85	11.10	10.13
6	10.67	10.68	12.22	11.19
Six Day $\overline{X}$	9.81	10.16	11.21	10.39
Six Day $\overline{X}_{S1\ S2,F}$			10.59	
Six Day $\overline{X}_{S1,S2,F}$			10.39	
Difference			0.20 kg	
Percent Difference			1.90 %	

The purpose of the first two days of testing was to remove the effects of learning, by establishing a stable baseline score for each of the criterion measures. As a large number of planned practice trials were executed on days one and two, changes in movement parameters due to practice may have occurred within blocks on these initial days. A second REANOVA was performed, in which the five blocks of ten trials were divided into two blocks of 25 trials on each of days one and two for analysis of the practice effects. It was expected that the movement time of the first block of trials on day one would be slower than the second block, with a similar pattern on day two. No significant practice effects were found over the first two days of practice in any of the movement parameters, as can be seen in tables 7 and 8.

Interrelationships between baseline criterion measures.

Pearson product-moment correlations were computed for all criterion measures, as well as for height, weight, and age. The correlations were computed using the six day mean of each subject for each measure. A correlation of .514 or greater was necessary for significance at the .05 level of confidence, and .641 at the .01 level of confidence. A matrix of the intercorrelations is presented in Table 9.

TABLE 7

VARIANCE ANALYSIS FOR MOVEMENT TIME AND ACCELERATION TIME CHANGES FOLLOWING TWO DAYS OF PRACTICE, CONSISTING OF TWO BLOCKS OF 25 FOREARM FLEXION MOVEMENT TRIALS ON EACH DAY

Source of Variation	d.f.	Movement Time			Acceleration Time		
		Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	3	670.5	223.5	1.11	79.0	26.3	.49
Subjects	14	15912.4	1136.6		2055.2	149.8	
Error	42	8436.3	200.9		2280.4	54.3	
Total	59	25019.2	424.1		4414.6	74.8	

TABLE 8

ANALYSIS OF VARIANCE FOR THE EFFECTS OF TWO DAYS OF PRACTICE, CONSISTING OF TWO BLOCKS OF 25 FOREARM FLEXION MOVEMENT TRIALS ON PERCENT ACCELERATION TIME

ource of ariation	d.f.	Sum of Squares	Mean Squares	F
leasures	3	144.5	48.2	.89
ubjects	14	2774.5	198.2	
rror	42	2271.2	54.1	
otal	59	5190.2	88.0	

TABLE 9

INTERCORRELATION MATRIX FOR A SIX DAY BASELINE MEAN OF EACH OF THE CRITERION MEASURES OF MOVEMENT TIME, ACCELERATION TIME, PERCENT ACCELERATION TIME, MAXIMUM ISOMETRIC FLEXION AND EXTENSION STRENGTH, AND THE HEIGHT, WEIGHT, AND AGE OF THE SUBJECT SAMPLE

	2	3	4	5	6	7	8
1. Movement Time (ms)	.48	-.90**	.12	.45	-.45	-.04	-.53*
2. Acceleration Time (ms)		-.06	.01	-.03	.04	-.24	-.37
3. Percent Acceleration Time (%)			-.12	-.48	.54*	-.03	.42
4. Maximum Isometric Flexion Strength (kg)				.54*	-.46	-.12	-.49
5. Maximum Isometric Extension Strength (kg)					-.22	.53*	-.56*
6. Height (cm)						.54*	.46
7. Weight (kg)							-.05
8. Age (yr)							

*$p < .05$
**$p < .01$

Percent acceleration time (PAT) correlated highly with movement time (MT), $r = -.90$. This indicates that the shorter the movement time, the greater the percentage of this movement time will be spent with the forearm positively accelerating. The percent of common variance between MT and PAT is .81.

Maximum isometric flexion strength was significantly correlated with maximum isometric extension strength at the .05 level of confidence, ($r = .54$). None of the other criterion measures were significantly correlated with each other. Although not significant at the .05 level of confidence, a correlation of .45 between maximum isometric extension strength and movement time was surprisingly high.

Effect of speed of forearm flexion movement trials on maximum isometric strength.

Maximum isometric flexion (FS) and extension strength (ES) were recorded at the beginning and end of each session. In order to determine the effect of a treatment on FS and ES, it was necessary to evaluate the effect of speed of forearm flexion movement trials on FS and ES. A repeated measures analysis of variance (REANOVA) was conducted to determine the significance of differences in FS and ES before and after 50 speed of forearm flexion movement trials on days one and two. These results are displayed in Table 10.

When the effects of 50 speed of forearm flexion movement trials on days one and two on the maximum isometric flexion (FS) and extension (ES) strength were analyzed, changes in ES were not found to be significant at the .05 level of confidence, while FS exhibited a significant decrease at the .05 level of confidence. When separate analyses were performed on day one and day two, the changes which occured in FS following 50 speed of forearm flexion movement trials on day one were not significant, while those on day two were significant at the .01 level of confidence. Table 11 contains these results. The actual decrease in FS was 1.18 kg on day two. As a significant decrease in FS did not occur on day one, nor in the combined results of days one and two; and, since subjects were never again asked to do more than 30 speed of forearm flexion movement trials during an experimental session, it was assumed that the speed of forearm flexion movement trials did not confound the treatment effects upon maximum isometric flexion strength. This assumption is supported by the work of Lagasse (37) and Wolcott (56) who found speed of forearm flexion movement trials to have no significant effects upon maximum isometric flexion strength.

TABLE 10

ANALYSES OF VARIANCE FOR THE EFFECTS OF 50 FOREARM FLEXION MOVEMENT TRIALS ON MAXIMUM ISOMETRIC FLEXION STRENGTH AND MAXIMUM ISOMETRIC EXTENSION STRENGTH MEASURED ON DAYS 1 AND 2

Source of Variation	d.f.	Isometric Flexion Strength			Isometric Extension Strength		
		Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	3	15.3	5.1	3.71*	12.6	4.2	2.41
Subjects	14	130.2	9.3		281.5	20.1	
Error	42	57.8	1.4		73.1	1.7	
Total	59	203.3	3.4		367.2	6.2	

*$p < .05$, indicates a significant decrease in isometric strength

TABLE 11

ANALYSES OF VARIANCE FOR THE EFFECTS OF 50 FOREARM FLEXION MOVEMENT TRIALS ON MAXIMUM ISOMETRIC FLEXION STRENGTH: MEASURES ON DAY 1 AND DAY 2 CONSIDERED SEPARATELY

		Flexion Strength Day 1			Flexion Strength Day 2		
Source of Variation	d.f.	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	1	5.0	5.0	3.49	10.3	10.3	9.90**
Subjects	14	50.3	3.6		103.4	7.4	
Error	14	19.9	1.4		14.6	1.0	
Total	29	75.2	2.6		128.1	4.4	

$^{**}p < .01$, indicates a significant decrease in isometric strength.

Isometric fatiguing exercise and movement parameters.

Influence of isometric fatiguing exercise regimen on maximum isometric strength. In an attempt to induce a change in the movement parameters, an isometric fatiguing exercise regimen consisting of 30 maximum voluntary contractions, was performed. One day consisted of isometric fatiguing exercise of the forearm flexors, (flexion fatigue), and one day of isometric fatiguing exercise of the forearm extensors, (extension fatigue). Before the effects of the isometric fatiguing exercise regimens on movement parameters are examined, their effects on maximum isometric strength must be substantiated. A repeated measures analysis of variance design (REANOVA) was used to assess the differences in maximum isometric strength before and after the isometric fatiguing exercise regimens. Flexion fatigue resulted in a decrease of 35.9% in maximum isometric flexion strength (FS) from pre to post treatment measures. This FS decrement averaged 3.71 kg, and was a significant decrease at the .01 level of confidence. Maximum isometric extension strength (ES), following extension fatigue treatment was .87 kg, or 8.3%, lower than the baseline ES. An ES decrement of .87 kg proved to be a significant strength decrement at the .05 level of confidence.

A REANOVA conducted to examine differences in the 30 maximum voluntary contractions of the isometric fatiguing exercise regimens revealed significant decreases in maximum isometric strength at the .01 level of confidence for both maximum isometric flexion strength (FS), and extension strength (ES). Further examination of the strength scores revealed a 26.9% decrease in FS from trial one of the isometric flexion fatiguing exercise reigmen to the post treatment measure. Comparison of trial one of the isometric extension fatiguing exercise regimen led to the surprising discovery of an increase in ES following the isometric extension fatiguing exercise regimen of 3.6% from trial one to the post treatment ES measure. A graphic presentation of the effects of the isometric fatiguing exercise regimens can be found in figure 7. Tables 12, 13, and 14 outline the results of the effects of the isometric fatiguing exercise regimens on maximum isometric strength.

A trend analysis was applied to the maximum isometric flexion and extension strength (FS, ES) scores during the isometric fatiguing exercise regimens. The trend analysis revealed significant linear ($p < .01$) and quadratic ($p < .05$) components in the flexion fatigue isometric strength curve for trials one through 30. The linear component accounted for 85.8% of the trend, while the quadratic component was responsible for 8.0% of the trend of the curve. Together, these two components account for 93.8% of the flexion

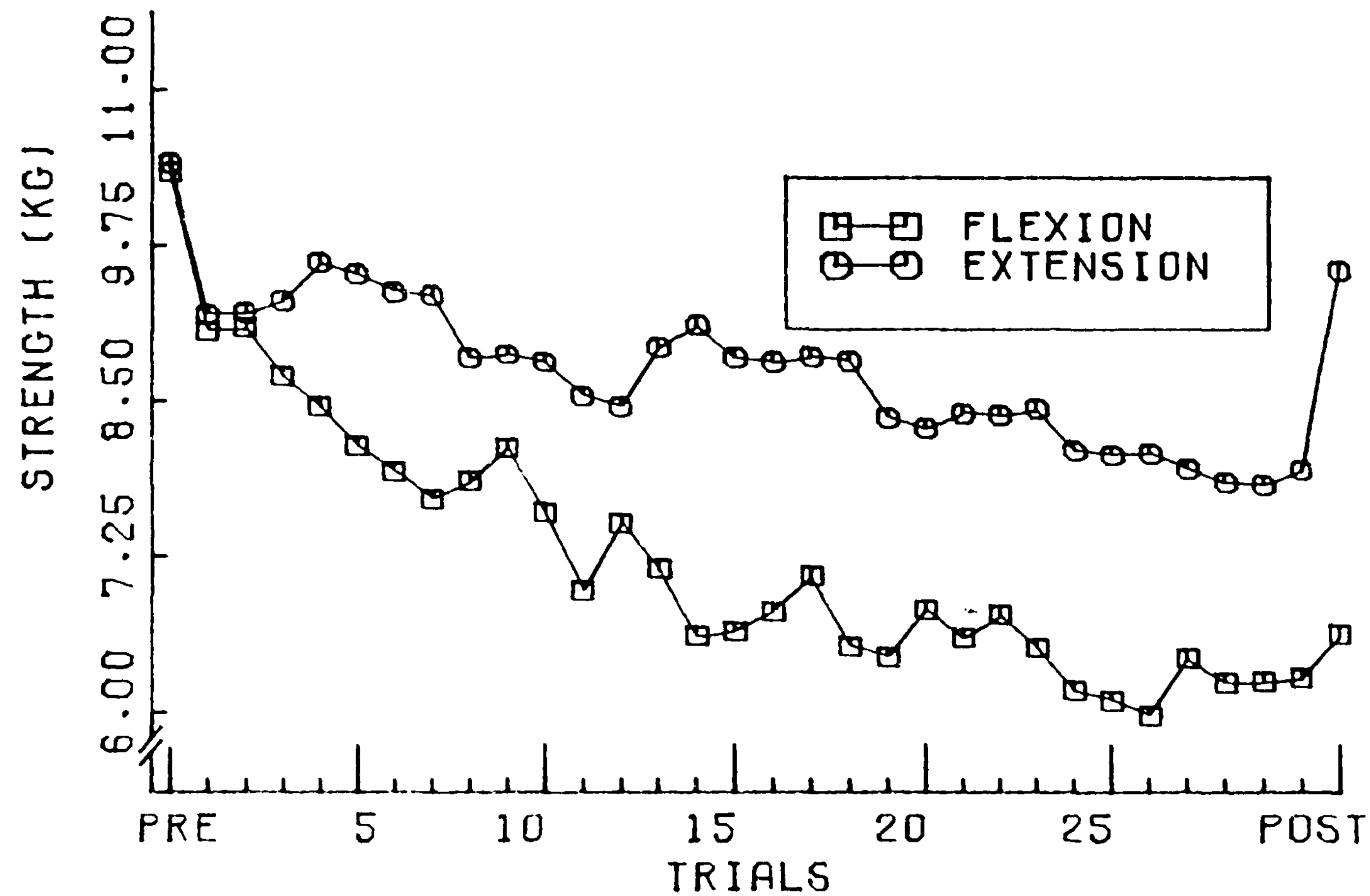

Figure 7. Maximum Isometric Flexion and Extension Strength Scores: Pre-Treatment Mean, 30 Trial Isometric Flexion and Extension Fatiguing Exercise Regimens, and Post Treatment Measure.

TABLE 12

ANALYSES OF VARIANCE FOR THE EFFECTS OF ISOMETRIC FLEXION FATIGUING EXERCISE ON MAXIMUM ISOMETRIC FLEXION AND EXTENSION STRENGTH: PRE TO POST TREATMENT STRENGTH MEASURES

		Isometric Flexion Strength			Isometric Extension Strength		
Source of Variation	d.f.	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	1	103.1	103.1	49.76**	10.3	10.3	3.22
Subjects	14	131.7	9.4		187.6	13.4	
Error	14	29.0	2.1		44.8	3.2	
Total	29	263.8	9.1		243.3	8.4	

$^{**}p < .01$, indicates a significant decrease in isometric strength.

TABLE 13

ANALYSES OF VARIANCE FOR THE EFFECTS OF ISOMETRIC EXTENSION FATIGUING EXERCISE ON MAXIMUM ISOMETRIC FLEXION AND EXTENSION STRENGTH: PRE TO POST TREATMENT STRENGTH MEASURES

Source of Variation	d.f.	Isometric Flexion Strength			Isometric Extension Strength		
		Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	1	12.9	12.9	8.84*	5.7	5.7	4.60*
Subjects	14	119.0	8.5		88.5	6.3	
Error	14	20.4	1.5		17.2	1.2	
Total	29	153.7	5.3		111.4	3.8	

*$p < .05$, indicates a significant decrease in isometric strength.

TABLE 14

ANALYSES OF VARIANCE FOR THE EFFECTS OF ISOMETRIC FLEXION FATIGUING EXERCISE ON MAXIMUM ISOMETRIC FLEXION STRENGTH AND ISOMETRIC EXTENSION FATIGUING EXERCISE ON MAXIMUM ISOMETRIC EXTENSION STRENGTH: TRIAL 1 - TRIAL 30

		Isometric Flexion Strength			Isometric Extension Strength		
Source of Variation	d.f.	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	29	358.6	12.4	11.39**	119.8	4.1	3.60**
Subjects	14	1326.2	94.7		1596.8	114.1	
Error	406	440.5	1.1		465.7	1.1	
Total	449	2125.6	4.7		2182.1	4.9	

**$p < .01$, indicates a decrease in isometric strength.

fatigue isometric strength curve trend. Trend analysis of the extension fatigue isometric strength curve revealed a significant ($p < .01$) linear component which accounted for 84.4% of the trend of the curve. The other components had no significant influence at the .05 level of confidence. These analyses of variance can be found in Table 15.

The isometric flexion fatiguing exercise regimen resulted in a significant decrease ($p < .01$) of maximum isometric flexion strength (FS), however, it did not affect maximum isometric extension strength (ES). The extension fatiguing exercise regimen resulted in a loss of FS which was significant at the .05 level of confidence, as well as a significant decrease in ES from trial one to trial 30. Tables 12 and 13 depict these results.

Effects of isometric fatiguing exercise on movement parameters. A repeated measures analysis of variance design was employed to evaluate changes in the movement parameters due to the isometric fatiguing exercise regimens. The isometric flexion fatiguing exercise (flexion fatigue), which produced at 35.9% decrease in maximum isometric flexion strength (FS) also resulted in significant changes in the movement parameters of movement time (MT), acceleration time (ACT) and percent acceleration time (PAT). MT was 29.81 ms or 16.4% slower; ACT was 30.17 ms, or 33.8%

TABLE 15

ANALYSES OF VARIANCE FOR ISOMETRIC FLEXION AND EXTENSION FATIGUE CURVE PATTERNS

Source of Variation	d.f.	Flexion Fatigue Curve Sum of Squares	Flexion Fatigue Curve Mean Square	Flexion Fatigue Curve F	Extension Fatigue Curve Sum of Squares	Extension Fatigue Curve Mean Square	Extension Fatigue Curve F
Within	435	783.0	1.8		565.5	1.3	
Trends	29	358.6	12.4	11.39	119.8	4.1	3.60
Linear	1	307.7	307.7	29.01**	101.0	101.0	9.42**
Quadratic	1	28.5	28.5	6.54*	0.7	0.7	0.34
Cubic	1	0.6	0.6	0.26	0.0	0.0	0.00
Quartic	1	0.1	0.1	0.23	0.1	0.1	0.04
Error	406	440.5	1.1		465.7	1.2	
Linear	14	148.5	10.6		150.2	10.7	
Quadratic	14	61.1	4.4		29.4	2.1	
Cubic	14	30.8	2.2		34.2	2.4	
Quartic	14	7.8	0.6		19.7	1.4	
Total	449	2125.6	4.7		2182.1	4.9	

*$p < .05$
**$p < .01$

TABLE 16

CHANGES IN THE CRITERION MEASURES OF MOVEMENT TIME, ACCELERATION TIME, PERCENT ACCELERATION TIME, AND MAXIMUM ISOMETRIC FLEXION AND EXTENSION STRENGTH FOLLOWING ISOMETRIC FLEXION AND EXTENSION FATIGUING EXERCISE

Measure	Flexion Fatigue Baseline 10 Trial $\bar{X}$	Flexion Fatigue Post Treatment 5 Trial $\bar{X}$	Extension Fatigue Baseline 10 Trial $\bar{X}$	Extension Fatigue Post Treatment 5 Trial $\bar{X}$
Movement Time (ms)	152.0	181.8 **	144.0	140.8
Acceleration Time (ms)	89.2	59.0 **	89.7	89.8
Percent Acceleration Time (%)	59.8	34.0 **	62.7	64.7
	3 Trial $\bar{X}$	1 Trial	3 Trial $\bar{X}$	1 Trial
Maximum Isometric Flexion Strength (kg)	10.34	6.63**	10.43	9.12*
Maximum Isometric Extension Strength (kg)	11.39	10.22	10.42	9.55**

*$p < .05$
**$p < .01$

TABLE 17

VARIANCE ANALYSIS FOR MOVEMENT TIME CHANGES FOLLOWING ISOMETRIC FLEXION FATIGUING EXERCISE AND ISOMETRIC EXTENSION FATIGUING EXERCISE

		Isometric Flexion Fatigue			Isometric Extension Fatigue		
Source of Variation	d.f.	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	1	6666.3	6666.3	20.56**	76.2	76.2	4.28
Subjects	14	7691.3	549.4		7818.8	558.5	
Error	14	4539.9	324.3		249.1	17.8	
Total	29	18897.5	651.6		8144.0	280.8	

**$p < .01$, indicates an increase in movement time.

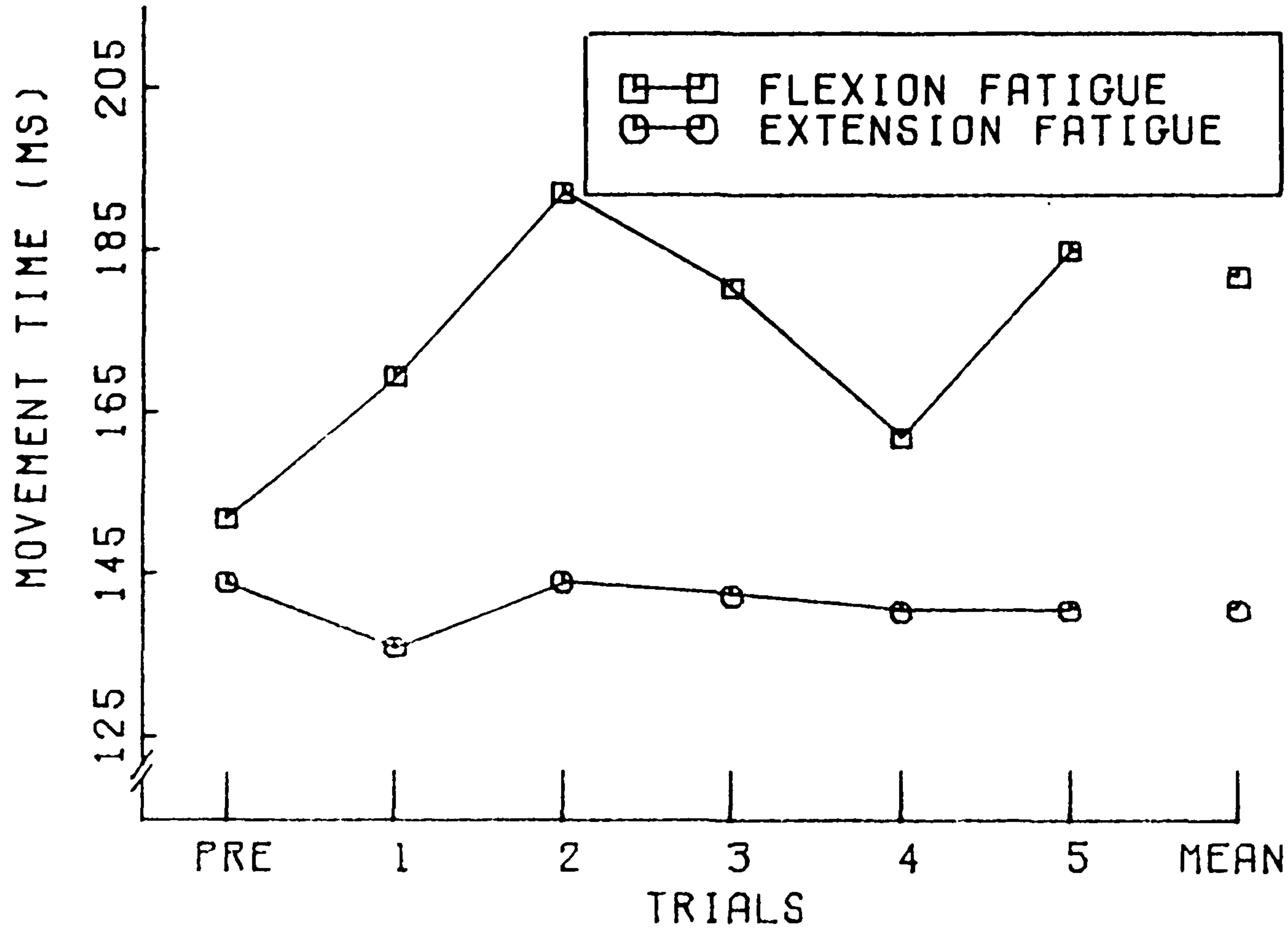

Figure 8. Effects of Isometric Fatiguing Exercise Treatment of the Forearm Flexors and Extensors on Movement Time.

TABLE 18

VARIANCE ANALYSIS FOR ACCELERATION TIME CHANGES FOLLOWING ISOMETRIC FLEXION FATIGUING EXERCISE AND ISOMETRIC EXTENSION FATIGUING EXERCISE

		Isometric Flexion Fatigue			Isometric Extension Fatigue		
Source of Variation	d.f.	Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	1	6828.2	6828.2	14.13**	0.1	0.1	0.01
Subjects	14	4859.2	347.1		473.6	33.8	
Error	14	6765.4	483.2		136.8	9.8	
Total	29	18452.8	636.3		610.5	21.1	

$^{**}p < .01$, indicates a significant decrease in acceleration time

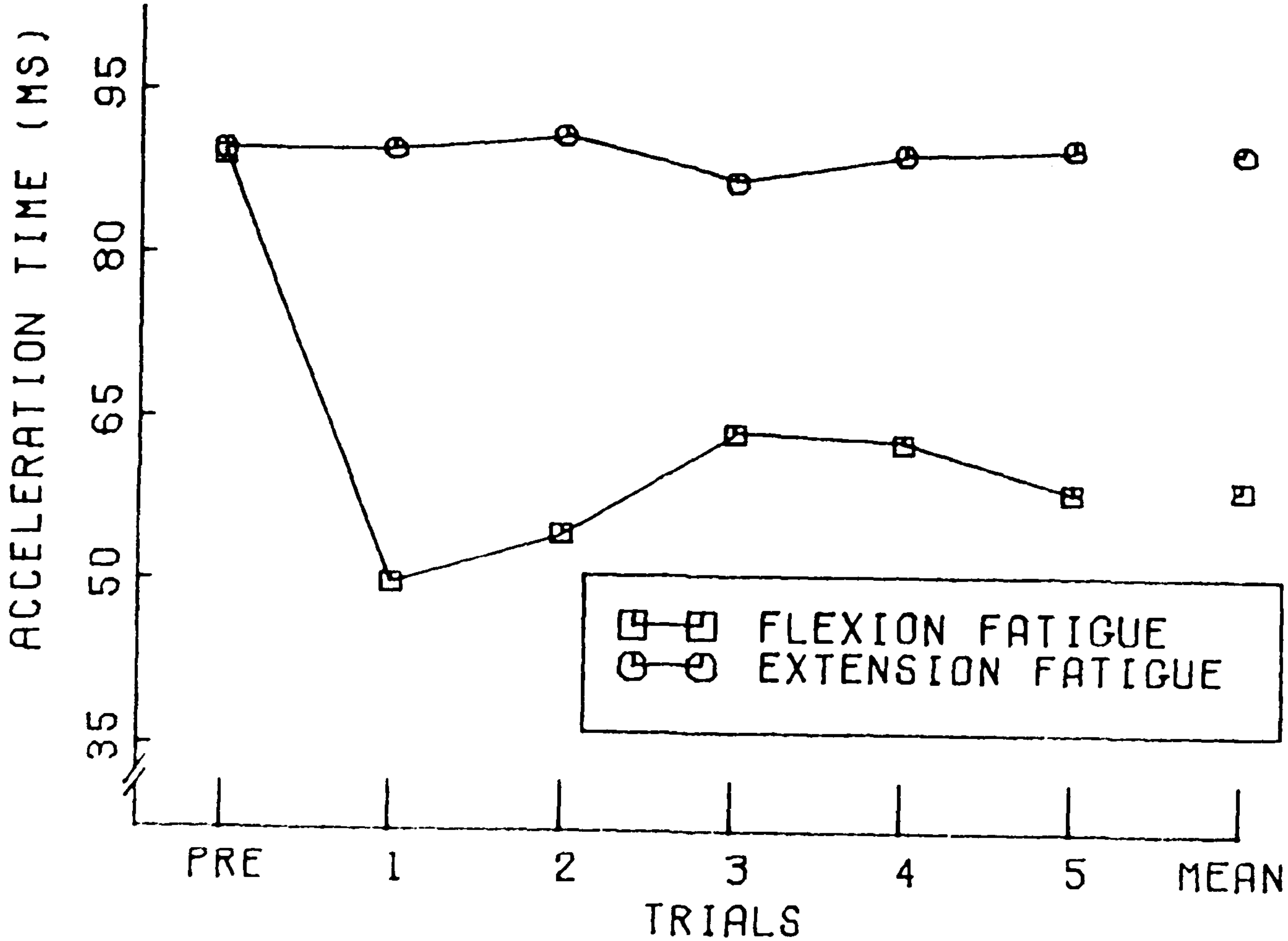

Figure 9. Effects of Isometric Fatiguing Exercise Treatment of the Forearm Flexors and Extensors on Acceleration Time.

TABLE 19

VARIANCE ANALYSIS FOR PERCENT ACCELERATION TIME CHANGES FOLLOWING ISOMETRIC FLEXION FATIGUING EXERCISE AND ISOMETRIC EXTENSION FATIGUING EXERCISE

Source of Variation	d.f.	Isometric Flexion Fatigue Sum of Squares	Isometric Flexion Fatigue Mean Square	Isometric Flexion Fatigue F	Isometric Extension Fatigue Sum of Squares	Isometric Extension Fatigue Mean Square	Isometric Extension Fatigue F
Measures	1	4989.7	4989.7	22.98**	31.2	31.2	3.18
Subjects	14	2269.6	162.1		1157.1	82.7	
Error	14	3040.0	217.1		137.6	9.8	
Total	29	10299.4	355.2		1326.0	45.7	

**$p < .01$, indicates a significant decrease in percent acceleration time.

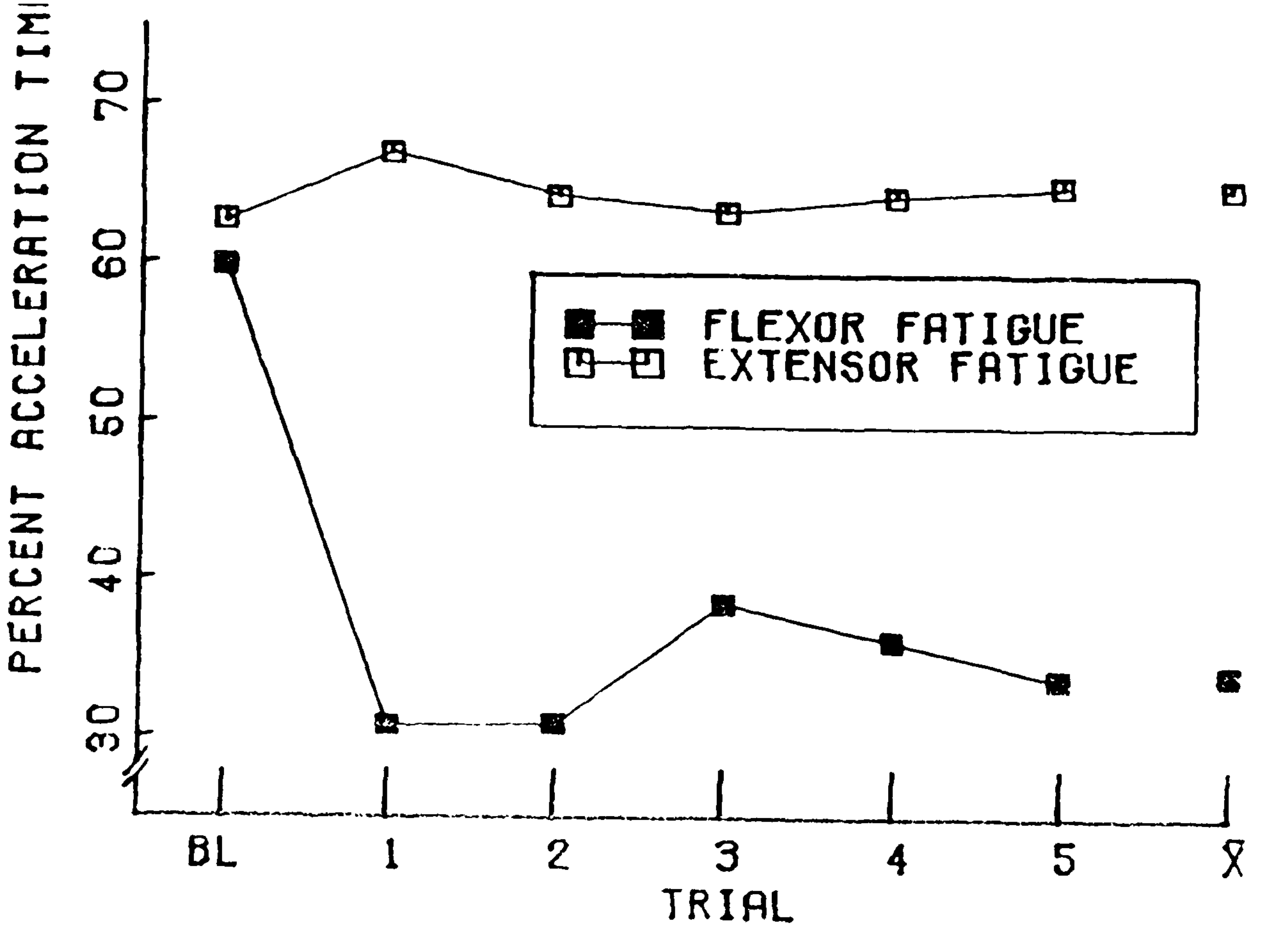

Figure 10. Effects of Isometric Fatiguing Exercise of the Forearm Flexors and Extensors on Percent Acceleration Time.

less; and PAT decreased by 25.8% following the isometric flexion fatiguing exercise regimen. The increase in MT, and decreases in ACT and PAT were significantly different from baseline measures at the .01 level of confidence. Although the isometric extension fatiguing exercise regimen (extension fatigue) produced a significant strength decrement at the .05 level of confidence from baseline to post treatment measures, extension fatigue did not significantly alter MT, ACT, or PAT at the .05 level of confidence. These results are presented in Table 16 and Figures 8, 9 and 10. The results of the repeated measures analyses of variance for the effects of isometric fatiguing exercise on MT, ACT, and PAT are illustrated in Tables 17, 18, and 19.

Effects of the tonic vibratory response on movement parameters and maximum isometric strength

The tonic vibratory response (TVR) was utilized as an experimental treatment in an attempt to alter the movement parameters of the speed forearm flexion movement (MSFFM). The forearm flexors and forearm extensors were vibrated at 100-110 Hz for 100 seconds before five MSFFM trials were performed, and the block of vibration-MSFFM was repeated four times on each of two days.

A repeated measures analysis of variance (REANOVA) design was used to examine the significance of differences observed in the movement time (MT), acceleration time (ACT), and percent acceleration time (PAT). A REANOVA was used to compare the baseline mean of 10 MSFFM trials to the mean of the 20 treatment MSFFM trials for each of the movement parameters during both flexion and extension TVR treatments. The results of the REANOVA's are presented in Tables 20, 21 and 22. The changes in movement parameters due to TVR treatments are graphically depicted in Figures 11, 12 and 13. TVR treatment of the forearm flexors (flexion vibration) resulted in an 8.1 ms increase in MT, which was significantly slower at the .05 level of confidence. Flexion vibration did not significantly alter ACT or PAT. TVR treatment of the forearm extensors (extension vibration) did not produce significant changes in any of the movement parameters.

The tonic vibratory response (TVR) is a time locked reponse, and has been shown to have a decreasing effect over repeated applications (4, 12). As it is possible that vibration may have a greater effect on the earlier blocks than on later blocks of speed of forearm flexion movement trials, a second REANOVA was utilized to test for differences in the block means. This second REANOVA did not indicate significant differences in any of the movement

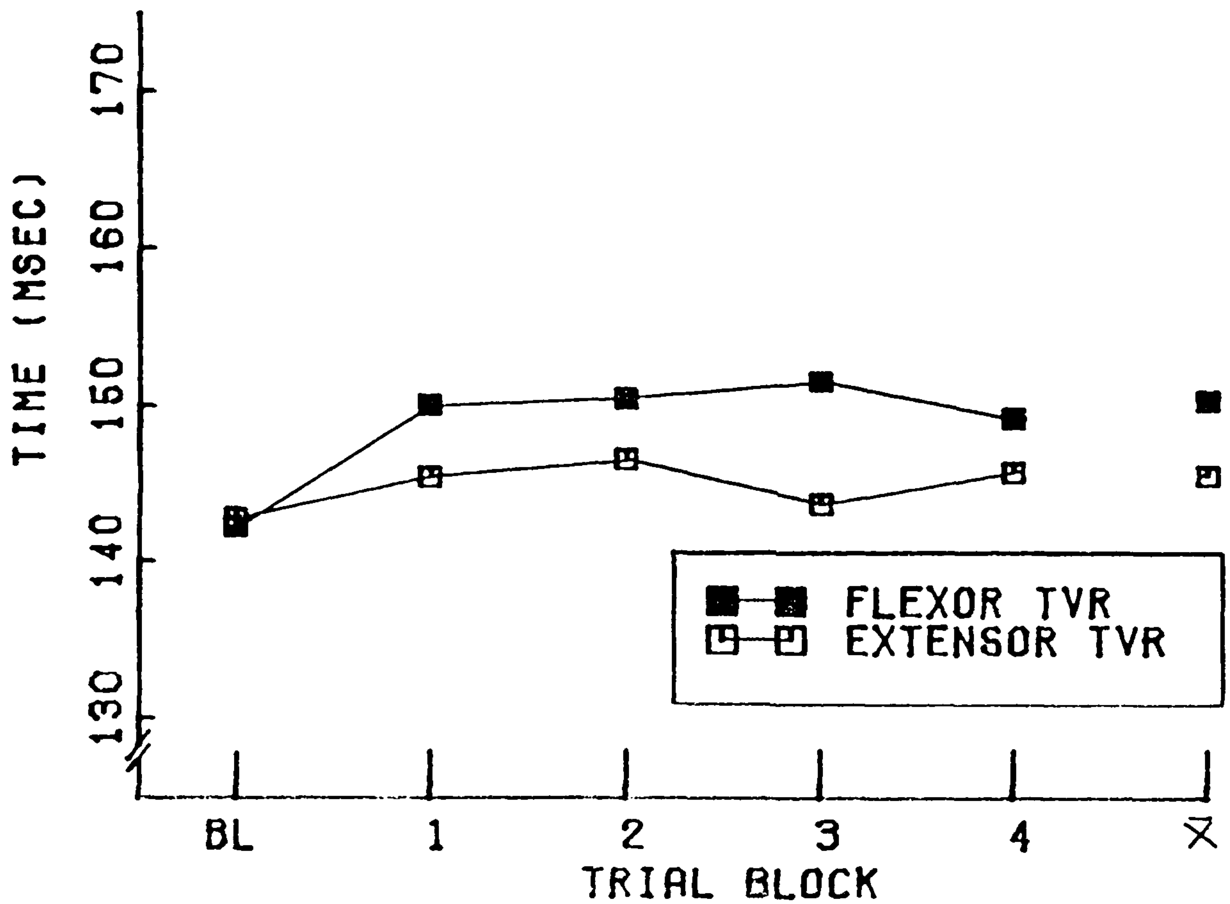

Figure 11. Effects of Tonic Vibratory Response Treatment of the Forearm Flexors and Extensors on Movement Time.

TABLE 20

VARIANCE ANALYSIS FOR MOVEMENT TIME CHANGES FOLLOWING TONIC VIBRATORY RESPONSE TREATMENT OF THE FOREARM FLEXORS AND EXTENSORS

Source of Variation	d.f.	Forearm Flexor TVR Sum of Squares	Forearm Flexor TVR Mean Square	Forearm Flexor TVR F	Forearm Extensor TVR Sum of Squares	Forearm Extensor TVR Mean Square	Forearm Extensor TVR F
Measures	1	488.0	488.0	7.70*	51.5	51.5	1.63
Subjects	14	4067.0	290.5		11062.8	790.2	
Error	14	887.6	63.4		443.8	31.7	
Total	29	5443.3	187.7		11556.5	398.5	

*$p < .05$, indicates a significant increase in movement time.

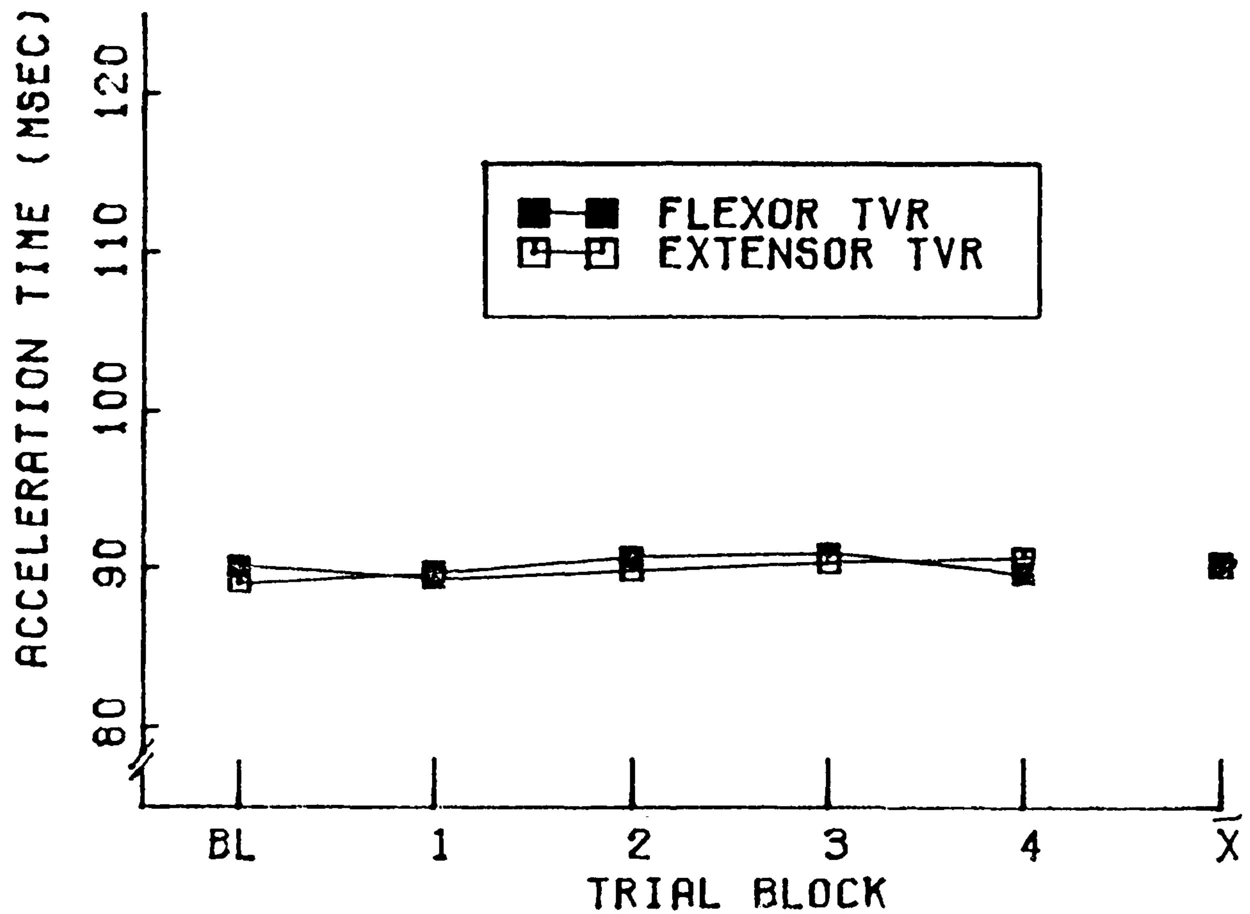

Figure 12. Effects of Tonic Vibratory Response Treatment of the Forearm Flexors and Extensors on Acceleration Time

TABLE 21

VARIANCE ANALYSIS FOR ACCELERATION TIME CHANGES FOLLOWING TONIC VIBRATORY RESPONSE TREATMENT OF THE FOREARM FLEXORS AND EXTENSORS

Source of Variation	d.f.	Forearm Flexor TVR			Forearm Extensor TVR		
		Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	1	12.8	12.8	4.44	0.0	0.0	0.00
Subjects	14	538.2	38.4		503.7	36.0	
Error	14	40.4	2.9		31.8	2.3	
Total	29	591.4	20.4		535.5	18.5	

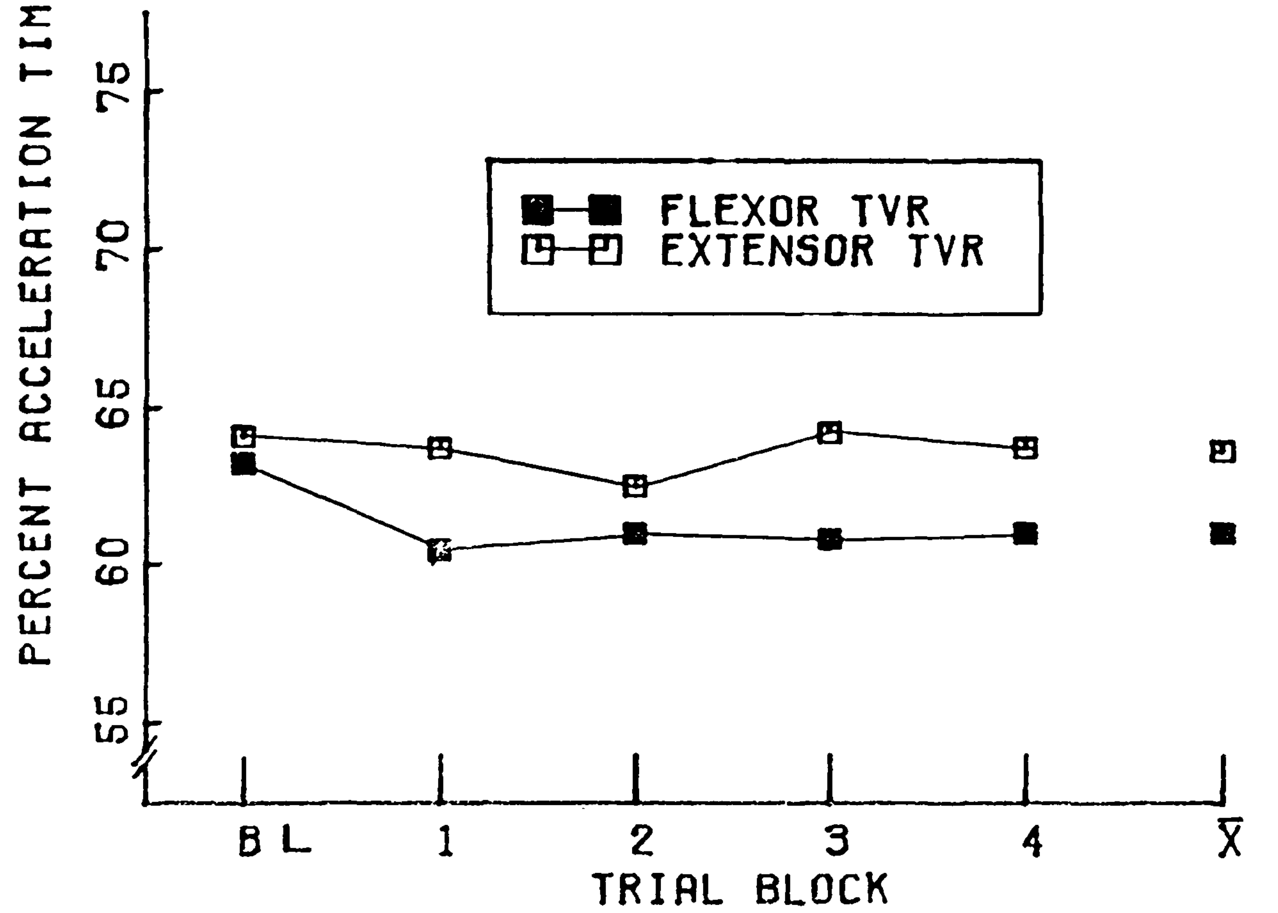

Figure 13. Effects of Tonic Vibratory Response Treatment of the Forearm Flexors and Extensors on Percent Acceleration Time

TABLE 22

VARIANCE ANALYSIS FOR PERCENT ACCELERATION TIME CHANGES FOLLOWING TONIC VIBRATORY RESPONSE TREATMENT OF THE FOREARM FLEXORS AND EXTENSORS

Source of Variation	d.f.	Forearm Flexor TVR Sum of Squares	Forearm Flexor TVR Mean Square	Forearm Flexor TVR F	Forearm Extensor TVR Sum of Squares	Forearm Extensor TVR Mean Square	Forearm Extensor TVR F
Measures	1	35.4	35.4	3.83	2.5	2.5	0.35
Subjects	14	713.6	51.0		1554.1	110.0	
Error	14	129.5	9.3		99.7	7.1	
Total	29	878.5	30.3		1656.3	57.1	

parameters following either flexion or extension vibration over blocks.

Flexion vibration did not significantly affect maximum isometric flexion or extension strength (FS, ES); however, extension vibration resulted in a 12.3% loss of ES, which was a significant decrease at the .01 level of confidence. Extension vibration did not significantly change FS. These results are presented in Tables 23 and 24. Table 25 outlines the changes resulting from TVR treatment of the forearm flexors and extensors.

TABLE 23

ANALYSES OF VARIANCE FOR THE EFFECTS OF TONIC VIBRATORY RESPONSE TREATMENT OF THE FOREARM FLEXORS ON MAXIMUM ISOMETRIC FLEXION AND EXTENSION STRENGTH

Source of Variation	d.f.	Isometric Flexion Strength			Isometric Extension Strength		
		Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	1	5.3	5.3	3.41	1.9	1.9	1.14
Subjects	14	198.0	14.1		178.1	12.7	
Error	14	21.9	1.6		23.5	1.7	
Total	29	225.3	7.8		203.5	7.0	

TABLE 24

ANALYSES OF VARIANCE FOR THE EFFECTS OF TONIC VIBRATORY RESPONSE TREATMENT OF THE FOREARM EXTENSORS ON MAXIMUM ISOMETRIC FLEXION AND EXTENSION STRENGTH

Source of Variation	d.f.	Isometric Flexion Strength			Isometric Extension Strength		
		Sum of Squares	Mean Square	F	Sum of Squares	Mean Square	F
Measures	1	0.2	0.2	0.08	12.1	12.1	10.51**
Subjects	14	167.4	12.0		215.8	15.4	
Error	14	41.0	2.9		16.1	1.2	
Total	29	208.6	7.2		244.0	8.4	

**$p < .01$, indicates a significant decrease in isometric strength.

TABLE 25

CHANGES IN THE CRITERION MEASURES OF MOVEMENT TIME, ACCELERATION TIME, PERCENT ACCELERATION TIME, AND MAXIMUM ISOMETRIC FLEXION AND EXTENSION STRENGTH FOLLOWING TONIC VIBRATORY RESPONSE TREATMENT OF THE FOREARM FLEXORS AND EXTENSORS

Measure	Forearm Flexor TVR		Forearm Extensor TVR	
	Baseline 10 Trial $\bar{X}$	Post Treatment 5 Trial $\bar{X}$	Baseline 10 Trial $\bar{X}$	Post Treatment 5 Trial $\bar{X}$
Movement Time (ms)	142.2	150.3 *	142.8	145.5
Acceleration Time (ms)	89.1	90.4	90.1	90.1
Percent Acceleration Time (%)	63.2	61.0	64.1	63.6
	3 Trial $\bar{X}$	1 Trial	3 Trial $\bar{X}$	1 Trial
Maximum Isometric Flexion Strength (kg)	9.87	9.03	9.37	9.19
Maximum Isometric Extension Strength (kg)	10.37	9.86	10.29	9.02**

$^{*}p < .05$
$^{**}p < .01$

Discussion

Power.

The statistical power of 96 percent found for the 15 subjects tested was greater than the pre-experimental power of 90 percent upon which sample size prediction was made. This indicates that the probability of accepting the null hypothesis when it was false was not as great. A decrease in the standard deviation of the movement time measure is the factor responsible for the increase in power.

Reliability of baseline measures.

Movement time. A high intraclass reliability coefficient of .90 was consistent with those reported by Wolcott (56), R = .96, and Lagasse (37), R = .88. The trial to trial variance of 69.5 was larger than that of Wolcott (56), 16.7, and smaller than the trial to trial variance of 96 reported by Lagasse (37). The class B movement utilized by Lagasse (37) required more skill to execute, and may not have been as easily replicated as the class A movement used in the present study and by Wolcott (56). Differences in the samples could account for the large discrepancy in the variance due to trials between the current study and Wolcott (56), since the same movement was utilized. Wolcott (56) used male subjects whose level of activity was considered to be above average.

Subjects in this study were female whose overall activity level could be considered average for their age group. Trained subjects may be more capable of replicating a maximum effort over a greater number of trials than subjects whose level of physical activity is not as great.

The movement time parameter yielded a lower variance due to trials than due to days. This lower variance due to trials combined with a high intraclass reliability coefficient demonstrates adequate consistency for the desired within day comparisons to be made.

Acceleration time. An intraclass reliability coefficient of .78 was obtained for the time to zero acceleration measure. Although the reliability coefficient was not as large as the coefficients obtained for the other measures, the trial to trial variance, variance due to days, and true score variance were all small indicating the consistency of the measure.

Percent acceleration time. The intraclass reliability coefficient for percent acceleration time (PAT) was .84 which is consistent with those of Wolcott (56), and Lagasse (37) of .85 and .81 respectively. Examination of the variance due to trials, days and the true score variance revealed that the PAT measure had greater consistency in the present study than in those of Lagasse (37) and Wolcott (56). A

TABLE 26

BASELINE MEASURES PRESENTED WITH THOSE REPORTED BY LAGASSE (37) AND WOLCOTT (56) FOR MOVEMENT TIME, PERCENT ACCELERATION TIME, AND MAXIMUM ISOMETRIC FLEXION AND EXTENSION STRENGTH

		Teves	Lagasse	Wolcott
Movement Time	6^2 trials	70	96	17
	6^2 days	88	103	73
	6^2 true score	184	214	175
	R_I	.90	.88	.96
Percent Acceleration Time	6^2 trials	16	34	283
	6^2 days	18	29	163
	6^2 true score	23	34	118
	R_I	.84	.81	.35
Maximum Isometric Flexion Strength	6^2 trials	1	3	48
	6^2 days	2	7	20
	6^2 true score	4	59	81
	R_I	.92	.97	.97
Maximum Isometric Extension Strength	6^2 trials	2	6	16
	6^2 days	2	13	48
	6^2 true score	5	104	211
	R_I	.94	.97	.98

comparison of the intraclass reliability coefficients and variance estimates obtained by Lagasse (37), Wolcott (56), and the present study for each of the measures can be made with attention to Table 26. The small variance components in the PAT measure indicates an adequate experimental design in that the number of days and trials were sufficient to detect changes in this measure.

Maximum isometric strength. The intraclass reliability coefficients for maximum isometric flexion and extension strength of .92 and .94 were comparable to those of Wolcott (56) and Lagasse' (37) which ranged from .97 to .98. As has been demonstrated in many studies (10, 33, 35, 55), maximum isometric strength is an extremely consistent measure. The consistency of the maximum isometric strength measure is also supported by the small variance components illustrated in Table 26.

Stability of baseline measures.

The baseline measures of movement time (MT), acceleration time (ACT), percent acceleration time (PAT), and maximum isometric flexion strength (FS), all proved to be extremely stable over the six day testing period. A repeated measures analysis of variance (REANOVA) revealed no significant differences in these baseline measures over the six days.

Although day to day comparisons of these movement parameters were not desired, the stability of MT, ACT, PAT, and FS would allow inter-day comparisons to be made.

Maximum isometric extension strength (ES) increased significantly at the .05 level over the six testing days. This was not wholly unexpected, as low strength females are likely to demonstrate increases in strength when asked to perform a series of maximum voluntary contractions (MVC) (32, 56). A second consideration is that untrained subjects may learn to produce greater tension with practice of the MVC, resulting in an apparent increase in strength over testing sessions.

Practice effects.

Examination of the effects of 50 speed of forearm flexion movement trials on each of the two practice days yielded non-significant changes in movement time, acceleration time and percent acceleration time. These results are not in accord with the generally accepted principle that practice improves performance. Based on previous studies (37, 46, 56) movement time was expected to decrease, while acceleration time and percent acceleration time increased. Wolcott (56) found a significant decrease of 13 ms in movement time from the day one mean to the day four mean; a total of 60 trials. Over this same period, Wolcott reported a significant increase in percent acceleration time of 17%. Lagasse (37) found a significant decrease in movement time of 63 ms, and a 14% increase in acceleration time from trial one to trial 100 during the first two days of practice. In agreement with Person (46), Lagasse (37) and Wolcott (56) reported changes in antagonist activity to be most responsible for changes in the movement parameters due to practice. Both studies (37, 56) found reductions in the amount of movement time the arm spent negatively accelerating, and attributed this to changes in the amount (37) and timing (56) of triceps activity.

Subjects in the present study may have achieved their maximum speed more rapidly than the subjects of the previous studies (37, 56), and, therefore, showed little improvement from block one of 25 trials on day one to block four on day two. Comparison of the movement time means on days one and two of the current study with those of Wolcott (56), who used an identical movement, reveal faster movement time scores in the current study for the first two days of 9 ms and 7 ms respectively. Perhaps, female subjects learned more quickly than their male counterparts and, having reached their maximum speed early in the series of practice trials, were unable to show a great deal of improvement.

The main purpose of the two initial practice days in the current study was to establish a stable baseline for the four treatment days to follow. Examination of the baseline scores on days four through six in Table 4 reveals changes of less than five units in all of the movement parameters. As no practice effects were observed, two days of practice may not have been necessary for the female subjects utilized in this study, but an extremely stable baseline was established.

Intercorrelation of baseline criterion measures.

Pearson Product moment correlations were calculated for all criterion measures, and movement time (MT) and percent acceleration time (PAT) were found to be highly negatively correlated, $r = -.90$ ($p < .01$). This correlation coefficient is in the same direction as those of Wolcott (56), $r = -.46$, and Lagasse (37) $r = -.79$, but of greater magnitude. It was expected that MT and PAT would be negatively correlated, because as MT becomes smaller, the average angular velocity of the movement must increase, and a greater percentage of the total movement time may consist of positive acceleration of the forearm. This relationship would hold even though no change occurred in the actual time to zero acceleration (ACT). Wolcott (56) did not report a significant relationship between MT and PAT. The range of ACT scores obtained by Wolcott (56) over 15 days of 106-148 ms was much greater than that found in the present study of 89-92ms. The regularity of the ACT scores in the current study allowed the movement time parameter to dictate changes in the PAT parameter almost completely. The reasons for the small range of ACT scores found in the current study are unknown, but may possibly be due to the use of female subjects.

A correlation of $r = .45$ was found between maximum isometric extension strength (ES) and movement time (MT) in the current study. Wolcott (56), and Lagasse (37) found non-significant correlations of -.56 and -.04 respectively. Although a correlation of .45 is not significant at the .05 level of confidence, it is greater than was expected based on previous studies. This indicates the importance of the antagonist muscle group in determining the speed of forearm flexion movement, because subjects with greater ES tended to move more slowly, as indicated by a greater MT. It cannot be stated with assurance that increased ES is accompanied by slower angular velocity, only that the results of this study have demonstrated a tendency for these measures to vary together in support of this hypothesis.

Based on the results of previous studies, a significant correlation between maximum isometric forearm flexion strength and movement time was not expected, and was not found. Although these results support much of the previous research (29, 30, 37, 56), it is still difficult to explain this phenomenon.

Movement time is inversely related to the angular velocity of a movement. As it is the function of muscle to produce motion, the maximum obtainable strength of a body part should correlate highly with the maximum speed of movement of that body part. This relationship is described by Newton's law of angular motion, where torque (T), a direct function of muscle tension, is equal to the moment of inertia (I) of an object multiplied by the angular acceleration (α) of that body part: ($T = I \cdot \alpha$). A muscle group able to produce greater torque should be able to accelerate a segment of a given moment of inertia more than a weaker muscle group, thus resulting in a greater angular velocity. In view of this relationship, forearm flexion movement time would be expected to be negatively correlated with maximum isometric flexion strength. A non-significant correlation of $r = .12$ was found in the current investigation. This is in agreement with the majority of the previous studies of isometric strength and movement time studies which found non-significant correlations ranging from $r = -.43$ to $.05$ (29, 37, 51, 56). As the acceleration of a limb is inversely proportional to its moment of inertia, some researchers considered that the low correlations between strength and speed might be due to a lack of consideration of limb mass. Attempts were made to correlate the strength-mass ratio of the arm with arm adduction movement time.

These attempts also failed to demonstrate a significant relationship between isometric strength and speed of movement with correlations ranging from $r = -.28$ to $.09$ (29,30,48).

In attempting to explain the lack of correlation between agonist strength and speed of forearm flexion movement in the current study, and many similar studies (10, 37, 47), a multitude of considerations become apparent, such as the differences between maximum isometric strength and functional strength, muscular coordination factors, and the validity of the measures used to represent speed and strength.

For the purposes of this discussion, the term functional strength will be used to describe the muscle torque one is able to voluntarily produce when performing a motor task. It should be recognized that this functional strength will vary with the demands of the movement. As angular velocity increases, the functional strength of the prime movers decreases (33, 55), the ability of a subject to produce torques comparable to their maximum isometric strength ceases upon movement initiation and it becomes increasingly difficult to produce large torques as the movement gains angular velocity.

The ability of a muscle to produce tension changes with the joint angle. 90° of elbow flexion is the position of greatest mechanical advantage for the forearm flexors. The effect of the mechanical advantage of the muscle during a speed of forearm flexion movement on the torque produced is probably not great due to a number of factors. Maximum velocity has already been reached (38), and the deleterious effects of speed on functional strength far outweigh the advantage of the position (33, 55). A second factor which serves to counteract the changes in torque resulting from changes in the mechanical advantage is the length of the muscle. As the forearm flexion movement progresses, the muscle length is decreased, and the ability to continue contracting decreases (55). These factors, decreasing tension with increasing speed and the decreasing length of the muscle, render functional strength subordinate to maximum isometric strength.

Factors concerning the muscular coordination and control of the limb must also be given consideration when examining the relationship between speed and strength. These factors include the fiber type of the muscle, the timing of the triceps contraction, and the motor unit activity of the involved muscle.

Knapik and Ramos (33) have proposed that fast twitch muscle fiber may be responsible for a maximum speed movement, while slow twitch muscle fiber is utilized to develop maximum isometric strength. It is also quite probable that the motor unit activity involved in these tasks are distinctly unique (2, 3, 25), in both the degree of synchronization and the amplitude of the muscle action potentials. Different patterns of motor recruitment for maximum speed and maximum isometric strength tasks may be a contributing factor in the speed-strength dilemma.

A third motor control factor which may influence the relationship between speed of movement and strength is the relative force and timing of the contraction of the antagonistic muscle. Lagasse (37) and Wolcott (56) studied this aspect of the speed of forearm flexion movement and noted that the contraction of the triceps occurred later in the forearm flexion movement as the movement was practiced. This delayed triceps contraction was accompanied by a faster speed of movement. As the electromyographic activity of the triceps was not monitored in the current study, it is not possible to determine the effects of the muscular coordination factors on the speed/strength relationship.

Consideration of all the factors affecting the relationship between maximum isometric strength and functional strength opens the possibility that speed of movement may not be directly related to maximum isometric strength. However, several researchers (18, 38, 42, 43), albeit a minority, have been able to demonstrate significant correlations between the speed of movement and isometric strength. In all cases, these researchers used angular velocity, rather than movement time, to represent speed. Movement time is representative of the average angular velocity, and should demonstrate a roughly inverse relationship with isometric strength to that of angular velocity. The current data did not reveal this relationship, nor did any previous research which attempted to correlate maximum isometric strength and movement time (29, 37, 51, 56). This question remains unanswered.

A non-significant correlation of r = .12 was found between maximum isometric flexion strength and forearm flexion movement time. This correlation is similar to those obtained in previous research efforts (37, 56) utilizing forearm flexion movement time to indicate average angular velocity.

Isometric fatiguing exercise and movement parameters.

Fatigue of a muscle group produces changes in the electromyographic activity of the muscle, and changes in the skilled motor performance of the muscle group. The effects of isometric fatigue on a class B forearm flexion movement were studied by Lagasse (37). The effects of isotonic fatigue on a class A forearm flexion movement were studied by Wolcott (56). It was the intent of this study to examine the effects of isometric fatigue on a class A forearm flexion movement in order to discriminate between changes in movement parameters due to movement selection and those due to the type of fatigue regimen utilized.

The effects of isometric fatiguing exercise of the forearm flexors and extensors on the maximum speed of forearm flexion movement were observed on separate days. For the purposes of discussion, this section will be broken into three parts. The first part will concern the shape of the maximum isometric strength curves during the isometric fatiguing exercise regimens, the second will contain a discussion of the effects of isometric flexion fatiguing exercise, followed by a discussion of the effects of isometric extension fatiguing exercise.

Isometric flexion and extension fatigue curve patterns. Examination of the variance analysis of flexion and extension fatigue curve patterns, reveals a marked difference between the two curves. The isometric flexion fatigue curve pattern contained a linear component which accounted for 85.8% of the curve, and a quadratic component which accounted for 8% of the curve. The quadratic component was not found in the extension fatigue isometric strength curve, where the only significant component was linear. This linear component accounted for 84.8% of the extension fatigue isometric strength curve. These results indicate that the isometric flexion fatiguing exercise regimen began to cause smaller strength decrements, or a leveling off towards the end of the 30 isometric contractions. Reaching a plateau level during an isometric fatiguing exercise regimen implies a greater depth of fatigue, than a fatigue curve that is purely linear in nature. As no plateau was seen in the isometric extension fatigue curve pattern, the depth of fatigue of the forearm extensors following isometric extension fatiguing exercise was probably not as great as that of the forearm flexors following isometric flexion fatiguing exercise.

Isometric flexion fatiguing exercise regimen. The isometric flexion fatiguing exercise regimen (flexion fatigue) resulted in a 35.9% strength decrement, or 3.7 kg based on pre and post treatment maximum isometric flexion strength (FS) measures, and was a significant decrease at the .01 level of confidence. The flexion fatiguing exercise regimen did not significantly change the maximum isometric extension strength measure. A 35.9% decrease in FS resulted in changes in all of the movement parameters which were significant at the .01 level of confidence. Movement time was 16.4% or 29.8 ms slower; acceleration time was 30.2 ms or 33.8% less; and percent acceleration time was 25.8% less following the isometric flexion fatiguing exercise regimen. These results support the work of Lagasse (37) who found an increase of 42 ms in movement time following a 40.9% decrease in FS which was due to an isometric flexion fatiguing exercise regimen. A concurrent 5% decrease in percent acceleration time following flexion fatigue was reported by Lagasse (37). Although the increase in movement time reported by Lagasse of 42 ms was larger than in the current study of 29.8 ms, the differences in the samples utilized must be considered. Lagasse (37) chose male subjects who were considered above average in their level of physical activity, with baseline maximum isometric strength scores approximately twice that of the female subjects in the current study. The higher strength male subjects were able to achieve a greater depth of fatigue than untrained, low strength, female subjects. A greater depth of fatigue of the forearm flexors on the part of Lagasse's male subjects manifested itself in a much slower movement time.

A second explanation of the larger increase in movement time demonstrated by Lagasse (37) lies in the differences in the movements chosen. Lagasse chose a forearm flexion movement which required subjects to arrest the arm after 75° of movement at maximum speed. The lack of a volitional stopping place made the movement used in the present study less complex than that of Lagasse. Fatigue results in a breakdown in the timing of a skill, and has a greater effect on more highly skilled movements, than on tasks which do not require the same degree of precision (8). The movement task used by Lagasse showed a greater increase in movement time following flexion fatigue, than that found in the present study because it was a more complex movement, and broke down more rapidly under fatigue conditions.

Using isotonic fatiguing regimens consisting of low repetition with maximum loading (high intensity), and high repetition with submaximum weight (low intensity), Wolcott (56) attempted to selectively fatigue the fast and slow twitch muscle fiber. Both intensities of fatigue produced significant increases in movement time of 25 ms and 29 ms for high and low intensity exercise respectively. Although the type of fatigue induced by Wolcott (56) was considerably different, the final effect of fatigue on the speed of movement was the same as that found in the present study. This does not indicate that the mechanisms involved are necessarily identical for isotonic and isometric fatigue, but that both isometric and isotonic flexion fatigue have a detrimental effect on the speed of forearm flexion movement.

Two possible mechanisms involved in slower movement times following the isometric flexion fatiguing exercise treatment (flexion fatigue) are desynchronization of agonist motor units, and a breakdown in the muscular coordination of the movement. The amount of time the forearm spends posi- tively accelerating; acceleration time, is determined by the amount of time the torque produced by the agonist is greater than the braking torque of the antagonist. Following isometric fatiguing exercise of the forearm flexors the acceleration time was decreased, which resulted in a slower speed of movement. Lagasse (37) reported increased agonist motor times following isometric fatigue of the forearm flexors. Longer motor times indicate a lack of agonist synchronization, as a longer time was needed to produce sufficient torque to initiate movement. Wolcott (56) reported an early appearance of the second burst of the biceps following isotonic flexion fatiguing exercise. She attributed this to a lack of motor unit synchronization, as the second burst of muscle action potentials were needed sooner to complete the forearm flexion movement. This is in agreement with Bagchi (5) who reported less synchronization of motor units as the speed of movement decreased.

A second factor which could be responsible for longer movement times following flexion fatigue is a breakdown in the muscular coordination of the movement. Lagasse (37) reported a longer biceps to brachioradialis latency following isometric flexion fatiguing exercise, which would indicate a change in the timing of the agonist muscles, however, no change occurred in the biceps to triceps latency.

Wolcott (56) also found a breakdown in agonist coordination, in that the biceps reached its peak activity earlier following high intensity isotonic forearm flexion fatigue.

In the current study, it was not possible to determine the mechanism of fatigue, as the myoelectric activity was not recorded. The results do support the hypothesis that isometric flexion fatiguing exercise results in a slower speed of class A forearm flexion movement.

Isometric extension fatiguing exercise regimen. Isometric extension fatiguing exercise (extension fatigue) resulted in an 8.3% decrement in maximum isometric extension strength (ES) from pre to post treatment ES measures, or a decrease of .87 kg. The strength scores during the isometric extension fatiguing exercise regimen decreased 1.25 kg, or 13.7%, from trial one through trial 30. A slight drop in ES from baseline measures to trial one of the extension fatigue series was not totally unexpected as subjects often subconsciously hold back at the beginning of a series of maximum voluntary contractions. This phenomenon is similar to the extra effort that may be exerted on the last few contractions in an effort to make a strong finish. The decreases in ES from pre to post treatment ES measures and from trial one to trial 30 of the extension fatigue series were both significant strength losses at the .05 level of confidence.

A repeated measures analysis of variance was used to determine the significance of changes in the movement parameters due to the isometric extension fatiguing exercise regimen (extension fatigue). Movement time, acceleration time and percent acceleration time showed no significant changes following the extension fatigue treatment. Fatigue of the forearm extensors was expected to reduce or delay the antagonistic torque, due to inhibition of the stretch reflex. Kroll (34) found longer reflex motor times following isotonic fatigue of the knee extensors. Isometric fatigue may delay the braking action of the forearm flexors by lengthening the triceps motor time during the stretch reflex, which results from a rapid forearm flexion movement. If the forearm flexors were able to maintain a larger torque, relative to that of the forearm extensors, for a longer time period, speed of movement should increase, which would be reflected in shorter movement times and longer acceleration times. The current study did not find these changes in movement parameters.

In a study of a class B forearm flexion movement and isometric extension fatiguing exercise, Lagasse (37) found movement time to be 8 ms faster following a 39.1% decrease in maximum isometric extension strength. Wolcott (56) examined the effects of isotonic extension fatiguing exercise on a class A forearm flexion movement, and found no significant differences in movement parameters following maximum isometric extension strength losses of 12-19%.

There are several possible explanations for these conflicting results. Perhaps the most important factor was the depth of fatigue. Lagasse (37) was able to demonstrate a faster speed of movement after a 39.1% decrease in maximum isometric extension strength (ES). The current study achieved an ES decrement of only 8.3%, while Wolcott was able to show ES losses of 12-19%; at best, not quite half of the ES loss achieved by Lagasse. Perhaps a greater depth of extension fatigue is necessary before it will affect maximum speed of movement parameters.

A second factor which must be considered, and is related to the depth of fatigue, is the rate of recovery of strength following a fatiguing exercise regimen. Examination of trial 30 and the post-treatment strength measure provides some insight into the amount of maximum isometric extension strength (ES) recovered during the speed of forearm flexion movement trials which followed the isometric extension fatiguing exercise regimen (extension fatigue). Lagasse (37) found a strength decrement of .5 kg from trial 30 of the extension fatiguing regimen to the post-treatment ES measure, which was not a significant difference. Lagasse's subjects did not recover ES during the maximum speed testing. In the present study there was an observed increase of 1.6 kg between trial 30 and post-treatment ES measures, following extension fatigue. This rapid recovery of ES supports the conclusion that no changes occurred in movement parameters following isometric extension fatiguing exercise due to an insufficient depth of extension fatigue, which allowed a rapid recovery of ES.

Lagasse (37) found no changes in maximum isometric flexion strength (FS) due to isometric extension fatiguing exercise (extension fatigue). Wolcott (56), using isotonic extension fatiguing exercise, and the isometric extension fatiguing exercise reigmen used in the current study both produced significant decreases in FS at the .05 level of confidence. These decreases in FS may have been due to co-contraction, which often occurs during unskilled tasks (46), or due to an attempt to stabilize the elbow during the extension fatiguing exercise regimen. The FS losses may have cancelled out the beneficial effects of extension fatigue on the speed of movement. Another possible explanation for the nonsignificant changes which occurred in the movement parameters involves the voluntary control of the forearm extensors. Kroll (34) found longer reflex motor times following isotonic fatigue of the knee extensors; however, the motor times during a knee extension reaction time task did not lengthen due to fatigue. The reaction task motor times did not lengthen because the volitional nature of the task allowed for compensatory measures to be taken, such as the use and synchronization of a larger number of motor units. Therefore, even if the depth of fatigue were sufficient to delay the stretch reflex, the voluntary braking contraction of the forearm extensors may occur earlier, or with greater synchronization in order to protect the elbow. A greater depth of fatigue may be necessary to prevent this compensation. Future research in this area should concentrate on stabilizing the elbow and achieving a greater depth of fatigue of the forearm extensors.

Effects of tonic vibratory response on movement parameters.

Much attention has been given to the effects of the tonic vibratory response (TVR) on various reflexes in man; particularly the Achilles tendon reflex, and the H-reflex (4, 9, 15). Research effort has also been focused on the methods which produce the greatest tension during vibration, but no information exists concerning the effects of the TVR on voluntary movement.

The tonic vibratory response (TVR) is an involuntary contraction of vibrated muscle fiber, and is believed to be caused by excitation of the muscle spindle primary endings. Vibration of the forearm flexors causes a tonic contraction to occur, which is generally accompanied by an inhibition of the forearm extensors (4, 32); the reverse facilitory-inhibitory relationship occurs when the forearm extensors are vibrated. The effects of the TVR have been observed to last up to 100 seconds following the removal of vibration. In view of these facts, a TVR elicited in the forearm flexors was expected to facilitate the forearm flexors and inhibit the forearm extensors. This was expected to increase the speed of movement by increasing the torque produced by the forearm flexors relative to the forearm extensors. Facilitation of the forearm extensors was expected to increase movement time due to increased drag of the forearm extensors and decreased torque of the forearm flexors.

In order to test this hypothesis the forearm flexors and extensors, on separate days, were vibrated for 100 seconds at a frequency of 100-110 Hz to elicit a TVR. As this was a standard frequency (4, 13, 19) of sufficient duration, it is assumed that a TVR was achieved in all subjects. A period of 100 seconds of vibration was immediately followed by five speed of forearm flexion movement trials, and this sequence was repeated four times.

The results of this investigation do not support the initial hypothesis. A tonic vibratory response (TVR) elicited in the forearm flexors (flexion vibration) resulted in an increase in movement time of 8.1 ms, which was significant at the .05 level of confidence. Acceleration time and percent acceleration time were not significantly affected by flexion vibration. A TVR elicited in the forearm extensors (extension vibration) yielded no significant changes in any of the movement parameters. Maximum isometric extension strength was 12.3% lower following the four treatments of extension vibration.

Tonic vibratory response induced in the forearm extensors. The tonic contraction of the muscle generally dissipates within a few seconds of removal of vibration, although the effects of the TVR on reflexive contractions last for up to 100 seconds of the post vibratory period (19, 32). Perhaps the facilatory effects of the TVR on the forearm extensors diminished too quickly to cause a significant decrease in the speed of movement. It is also possible that voluntary muscular effort overrides any effect the TVR may have on the speed of forearm flexion movement. The TVR is not a strong reflex, and subjects are generally able to prevent the contraction from occurring if provided with a visual readout of the tension (13, 15). It seems likely that the strong voluntary contraction of the forearm flexors to produce a maximum speed of forearm flexion movement could overcome the deleterious effects of a TVR induced in the forearm extensors.

A decrease in the maximum isometric strength of the forearm extensors of 12.3% could also be responsible for the lack of change in movement parameters following TVR treatment of the forearm extensors (extension vibration). This degree of fatigue may have cancelled out the facilitory effects of extension vibration on the braking power of the forearm extensors. A fatigued, albeit facilitated, forearm extensor muscle group combined with an inhibited forearm flexor muscle group, which was able to compensate for the inhibitory influence of vibration resulted in maintenance of the speed of forearm flexion movement following extension vibration.

<u>Tonic vibratory response (TVR) in the forearm flexors.</u> An increase in movement time of 8.1 ms following TVR treatment of the forearm flexors (flexion vibration) is more difficult to explain than no reaction from extension vibration, as movement time was expected to decrease when the forearm flexors were facilitated, and the forearm extensors inhibited. The TVR is a tonic contraction of the vibrated muscle and has a facilitory effect, with a concomitant inhibition of the antagonist muscle. Perhaps this tonic contraction can also result in fatigue of the vibrated muscle. Maximum isometric flexion strength (FS) decreased .84 kg, or 8.5%, following flexion vibration treatment, while maximum isometric extension strength (ES) decreased by 1.4 kg, or 12.3%

following extension vibration treatment. The decrease in ES was significant at the .01 level of confidence. It is clear that these strength decrements are not due to speed of forearm flexion movement trials, because 50 speed of forearm flexion movement trials in five blocks of ten had no significant effect upon maximum isometric strength during the initial practice day. The 20 speed of forearm flexion movement trials would, therefore, not be responsible for the decrements in maximum isometric strength. A decrease in FS has been found to increase movement time, as previously reported in this study, and by others (37, 56). It is, therefore, possible that an increase in movement time following flexion vibration was the result of a vibration induced FS loss which cancelled out the facilitory/inhibitory effects of vibration on the biceps/triceps coordination.

Vibration is used clinically to help spastic and paretic patients, who have little voluntary control over their affected musculature. In theory, the facilatory and inhibitory effects of vibration should be a useful therapeutic tool in working with patients who lack muscular control; however, no evidence exists to substantiate this. A second major problem with vibration therapy is a decreasing treatment effectiveness, which is more pronounced over days than within days. Goldfinger and Schoon (22) reported significant decreases in the TVR over repeated trials, both within and across days. Johnston, Bishop and Coffey (32) found the tension to be reproduceable over trials within days, but not over days. The decreasing TVR over days may be due to a long lasting inhibition, or to some type of habituation mechanism (22); in either case, vibration treatments applied over days result in a decreased TVR with each application (22, 32). A continued decreasing response greatly limits the practicality of the TVR as a therapeutic tool, as each treatment would reap smaller benefits. The within day reproduceability is sufficient for experimental purposes (22), but more research is needed to improve the repeated effectiveness of vibration treatment if it is to be used as a therapeutic tool.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

In order to examine the components of fast human movement, a study was undertaken to assess the influence of local isometric muscular fatigue and the tonic vibratory response (TVR) on the maximum speed of forearm flexion movement. The alterations in forearm flexion movement time, acceleration time and percent acceleration time, as well as changes in the maximum isometric strength of the elbow flexor and extensor muscle groups due to isometric fatiguing exercise and TVR treatments were examined in order to shed some light on the mechanisms involved in fast movement.

Measures of speed of forearm flexion and maximum isometric elbow flexion and extension strength under isometric fatiguing exercise and TVR treatment conditions were observed in fifteen college age female subjects. Each subject participated in six testing sessions over a two week period. The first two sessions involved stabilization of all criterion measures: movement time, acceleration time, percent acceleration time, and maximum isometric elbow flexion and extension strength. Following the initial practice days, two sets of treatment conditions, balanced over subjects and days, were imposed. Baseline measures were recorded prior to treatment of isometric elbow flexion or extension fatiguing exercise and TVR treatment of the elbow flexors or extensors. Post treatment measures of movement parameters and maximum isometric strength were recorded, immediately following treatment. The data were analyzed to determine the effects of each treatment on the baseline measures of forearm flexion movement parameters and maximum isometric elbow flexion and extension strength.

Results

This section will summarize the results obtained from the statistical analyses, which were described in greater detail in Chapter IV.

1. The movement parameters of movement time, acceleration time and percent acceleration time exhibited no significant practice effects.
2. Percent acceleration time was significantly correlated with movement time, $r = -.90$, at the .01 level of confidence.
3. An isometric forearm flexion fatiguing exercise regimen produced a 35.9% decrease in maximum isometric elbow flexion strength decrement resulted in a 29.8 ms increase in movement time, a 30.2 ms decrease in acceleration time, and a 25.8% drop in percent acceleration time. These changes in the movement parameters and maximum isometric elbow flexion strength were significant at the .01 level of confidence.
4. The isometric forearm extension fatiguing exercise regimen caused a .87 kg decrease in maximum isometric forearm extension strength from pre to post treatment measures, which was a significant decrease at the .05 level of confidence. No significant changes in the

movement parameters of movement time, acceleration time, or percent acceleration time occurred due to isometric forearm extension fatiguing exercise.

5. The tonic vibratory response (TVR) treatment applied to the forearm flexors resulted in a significant increase, ($p < .05$), in movement time of 8.1 ms, but did not significantly alter acceleration time nor percent acceleration time.

6. The tonic vibratory response treatment applied to the forearm extensors produced no significant changes in any of the movement parameters.

7. Maximum isometric elbow flexion and extension strength are not highly correlated with the speed of forearm flexion movement, as represented by movement time.

Conclusions

On the basis of the current study it can be concluded that:

1. Female subjects do not require two days of 50 speed of forearm flexion movement trials in order to stabilize movement parameters.
2. Isometric fatiguing exercise treatment of the elbow flexors influences the speed of elbow flexion movement causing the movement to be performed more slowly.
3. Isometric fatiguing exercise treatment of the elbow extensors does not influence the speed of forearm flexion movement.
4. A tonic contraction induced by vibration of the elbow flexors produces a fatigue-like slowing of the speed of forearm flexion movement.
5. A tonic contraction induced by vibration of the elbow extensors produces no changes in the speed of forearm flexion movement.

Recommendations for Further Study

The mechanisms involved in the production of fast human movement have not, as of yet, been delineated, and there are many avenues of approach open to the investigator in this area.

Although attention has been given to the electromyographic (EMG) activity of the agonist and antagonist musculature, no attempt has been made to quantify and compare the EMG activity of a movement at varying speeds, and under a variety of treatment conditions. This type of research would provide descriptive information concerning the production of a maximum speed movement, as well as methods of muscular compensation to preserve the quality of movement under stress, imposed by various treatments.

The development of isokinetic exercise machines suggests many possibilities for research into the relationship between torque and angular velocity through a full range of movement. Isokinetic machines could also be used to produce isotonic fatigue. The information concerning the torque produced throughout the movement combined with advanced EMG recording techniques could also provide information concerning the effects of load on the muscular coordination of fast movements. Perhaps as isokinetic machinery becomes more advanced, it will be possible to determine the torque produced through a full range of motion at maximum speed with a minimal amount of resistance.

The tonic vibratory response (TVR) effects upon the musculature involved in a speed of forearm flexion movement need to be examined under a variety of treatment conditions. For example, the amount of time the vibration is applied should be decreased in order to discriminate between the effects of TVR and possible fatigue induced by a sustained tonic contraction. Another suggested method of treatment application would be to examine the effects of TVR induced during the movement, rather than just prior to movement.

The implications of various types of training regimens on developing speed of movement is suggested for study. Biofeedback training techniques could be employed to assist the performer in improving his motor control and coordination. The effects of athletic training programs for specific sports on the speed of movement could be examined on a pre-post season basis, or on a long range, beginner to experienced performer basis. As speed of movement is a key element in a majority of competitive sports, it is important to determine the validity and effects of current sports training techniques on the speed of human movement. A comparison between the muscular coordination of power and endurance athletes could be made to determine the relationship of fiber type and the effects of specific training regimen on the maximum speed and muscular coordination of movement.

As the results of any research are only valid for the sample selected, it is necessary to examine the muscular coordination factors involved in a speed of forearm flexion movement in all major sectors of the population. Little information is available on the coordination of fast movements in young children, or the elderly. This information would be valuable in understanding the maturation process of muscular coordination, and so of the nervous system.

The results of all the proposed studies would serve to clarify the role of the nervous system in the control of movement.

APPENDIX B

SAMPLE SIZE ESTIMATION

Case four formula: Cohen (11)

where $d = \frac{d'4}{\sqrt{1-r}}$ and $d'4 = \frac{m_x - m_y}{6}$

Movement Time:

$m_x - m_y$ = 10% mean value		=	15
	6	=	18.1
	r	=	.93
	d'4	=	.80
	d	=	11.43
Power		=	90%

POST MORTEM POWER ANALYSIS

Movement Time:

$m_x - m_y$ = effect size			15	
	6	=	14.3	
	r	=	.90	
	d'4	=	1.05	
	d	=	3.32	
Power		=	.96	$p < .05$

APPENDIX C

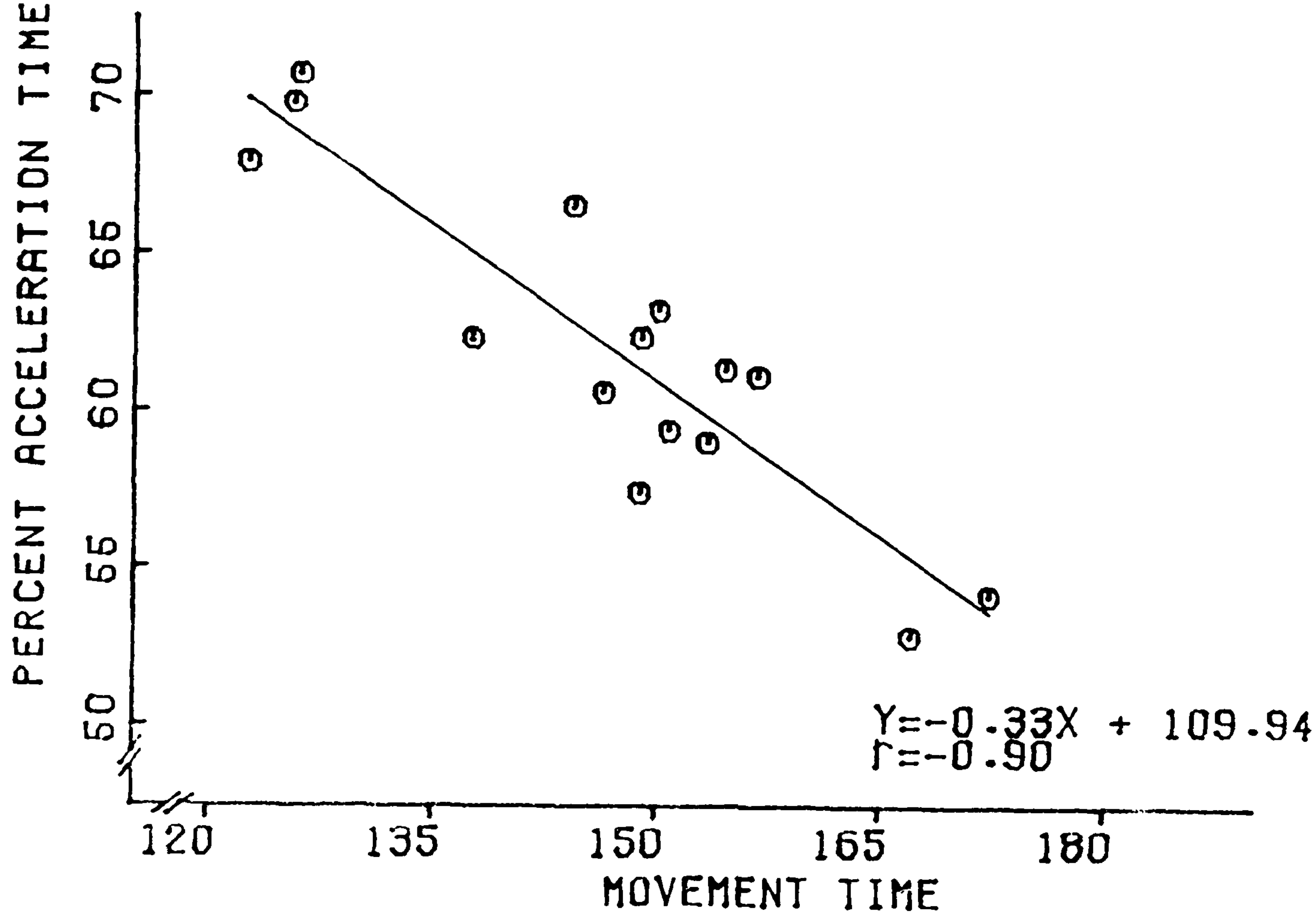

Figure 14. Product-Moment Correlation Between Movement Time and Percent Acceleration Time.

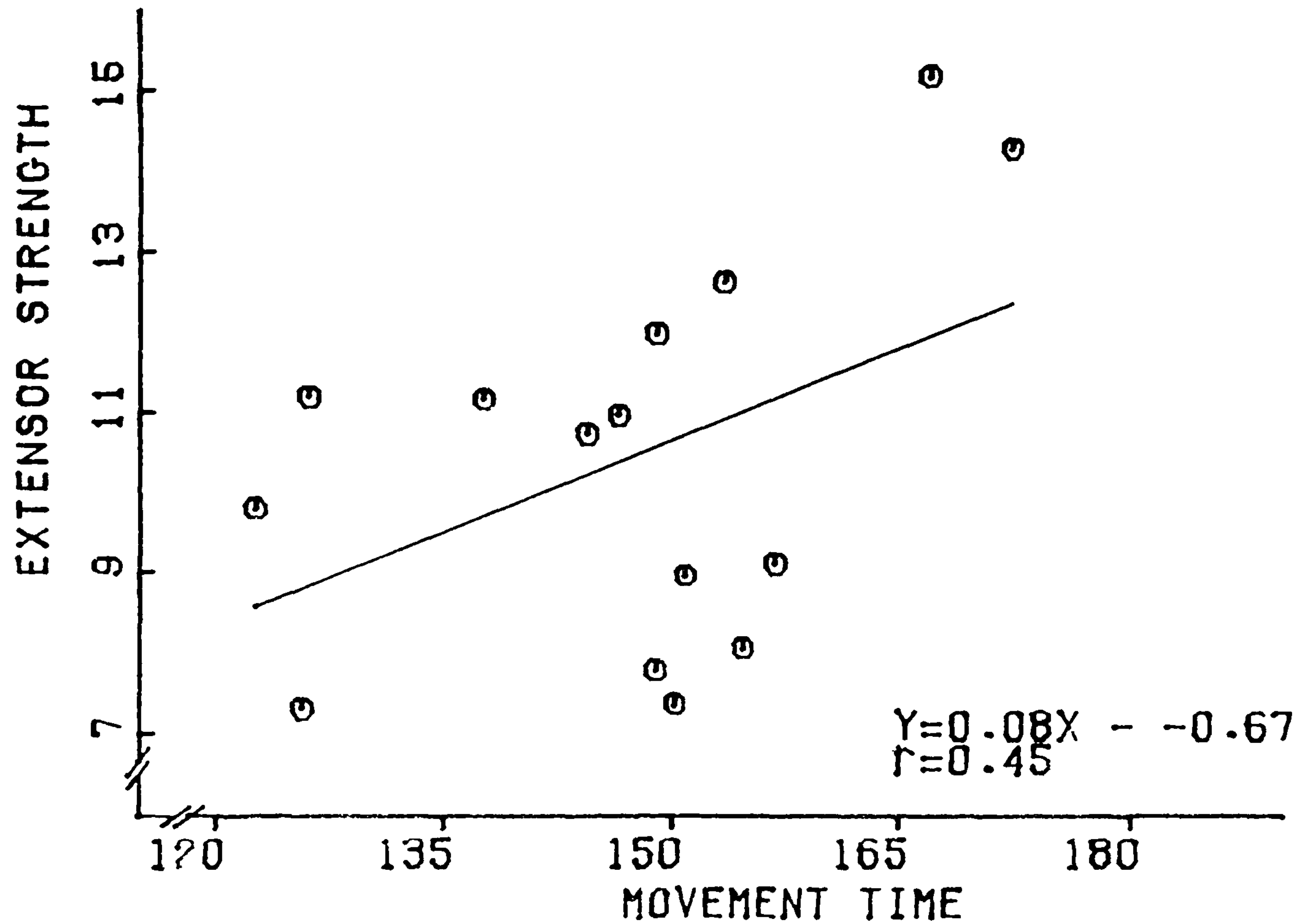

Figure 15. Product-Moment Correlation Between Movement Time and Maximum Isometric Extension Strength.

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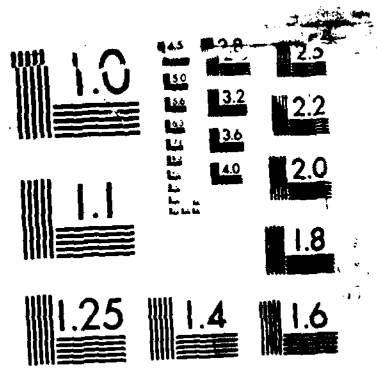

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